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STRUCTURE OF THE ANORTHOSITE BODY IN THE ADIRONDACKS

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Introduction.—In No. 3 of the current volume of this *Journal* Dr. N. L. Bowen has discussed "The Problem of the Anorthosites" in a very suggestive and important paper with whose general thesis I find myself in quite hearty accord. It seems to me that the process of formation of anorthosite, as there outlined, is quite the most probable method yet suggested; and I am quite in agreement with the explanation of the general protoclastic and granulated textures which all large bodies of anorthosite exhibit.

When, however, Dr. Bowen comes to consider the universal, or usual, field relations between anorthosite and the accompanying bodies of syenite, and suggests in that connection a structural relationship of these rocks in the Adirondack region, the field facts there, as known to me, seem to be in direct conflict with certain features of that suggestion. The chief point on which we differ does not seem to me in any way to vitiate his main argument, but it does seem desirable to bring it out plainly.

His argument is substantially as follows: that there is (*a*) an intimate connection of syenite with anorthosite wherever the latter is found, as shown by the abundance of rock types intermediate

between the two and by the rarity of exposures showing an intrusive relation of the one with the other; (*b*) an intimate association of syenite with Grenville in many places, as contrasted with the anorthosite areas which are comparatively free from Grenville inclusions; also (*c*) the frequent occurrence of Grenville beds overlapping syenite in moderately undisturbed fashion, after the manner of a roof.

Because of the latter relation Bowen argues that it is difficult to picture the syenite and anorthosite as conventional batholiths. He says:

> It is necessary to imagine an early intrusion of a huge plug of anorthosite, followed by an intrusion of syenite which took the form of a hollow cylinder, circumscribing it and invading it only peripherally. All this must take place without throwing the Grenville series into appressed folds, indeed without significant folding of any kind. It is then necessary to imagine that erosion removed every vestige of a roof from the small, interior anorthosite area, and left great stretches of it throughout the broad syenite-granite belt that surrounds it.[1]

Because such relationships seem to him improbable he suggests that the Adirondack eruptive complex consists of a sheetlike mass, or huge laccolith, with syenite overlying anorthosite.

The purpose of this rejoinder is to point out that we are not limited solely to the two alternatives outlined above, and that the data obtained in the field seem to me definitely to contradict the hypothesis that the Adirondack region is composed of a single great sheetlike mass, with syenite overlying anorthosite and bearing all the Grenville exposures of the region rooflike on its back.

Distribution of anorthosite and syenite.—The Adirondack anorthosite is massed in a single great body, rudely heart-shaped, with the apex toward the south. There are a number of small, outlying masses, some of which have some bearing on the questions under discussion. But in addition the continuity of the main mass is interrupted by two considerable *inlying* bodies of other rock, one in the Lake Placid region and one near Keene. Both of these are shown on the state map. At the time when Kemp prepared this

[1] *Jour. Geol.*, XXV, No. 3, 223.

portion of the map we were just beginning to recognize the green syenite of the region as a later intrusive and to separate it from the main body of the gneiss in mapping; hence comparatively little syenite is shown as such on this map, and much of what is there mapped as gneiss has been since shown to be syenite also. The two inliers referred to are mapped as gneiss; but Kemp's description of the rocks clearly shows that the Placid inlier consists largely or wholly of syenite and that the same rock is represented in the Keene inlier.[1] Both of these inliers are entirely surrounded by anorthosite, and lie well within the mass.

By comparison with the anorthosite the syenites occur in separate masses of smaller size, usually much smaller, and there is a large number of such masses. Some of these directly border the anorthosite, but there is nothing like a continuous rim of syenite about it. These syenite masses range throughout the entire region and, in my experience, are no more abundant near the anorthosite than they are away from it. The anorthosite lies in the eastern portion of the Adirondack pre-Cambrian, and its relationships to other rocks on its eastern margin are largely hidden by downfaulting and by the cover of Champlain Paleozoics. But to the west and south abundant syenite ranges away to distances of 60 or 70 miles beyond the anorthosite border; and such pre-Cambrian outliers as those at Little Falls and Middleville bear witness that it runs an unknown distance beyond the pre-Cambrian margin under the Paleozoic cover.

The point here made is that the syenite is spottily distributed over the region, is no more abundant near the anorthosite than it is away from it, and extends so far from the surface exposures of anothorsite that the latter must be given an enormous lateral extent underground, on the supposition that the two constitute a sheetlike mass, with the anorthosite beneath. It is candidly admitted that this point has no particular value if Dr. W. J. Miller's conception of the constitution of the Adirondack pre-Cambrian complex is the correct one. His view is that this complex consists entirely of a foundation of intrusives of the anorthosite-syenite-granite group, upon which fragments of the Grenville

[1] *Bull. 21, N.Y. State Mus.*, pp. 55–56.

cover locally persist.[1] My view is that a complex of Grenville, resting on orthogneiss, existed in the region at the time of the intrusion of the anorthosite-syenite group, that much of this orthogneiss still remains in the region, and that the later intrusives broke through this complex in separate masses, instead of forming one great body.[2] Obviously the presence of a great laccolith constituting the entire region, such as Bowen postulates, is much more possible under the former view than under the latter.

It is quite true that many of the syenite masses are much mingled with Grenville and that the anorthosite area contrasts rather sharply in this respect, as Bowen contends. And I am quite in accord with his view that there has been deeper erosion in the eastern Adirondacks, where the anorthosite occurs, than there has been to the west and south, where the syenite bodies occur, and have repeatedly so stated. Nor am I particularly disposed to quarrel with the view that the anorthosite mass may be laccolithic instead of batholithic in structure. I do not know which it is. The mass has certainly great thickness, since the climb up Mt. Marcy furnishes a 3,500-foot section of pretty clean anorthosite, with no particular indication that the entire thickness may not be vastly greater; then allowance must be made for at least an equal thickness of gabbro and pyroxnite underneath and for an unknown thickness of overlying syenite, since eroded away. Nevertheless, a sheet structure is entirely possible.

Differentiation of the anorthosite body.—If I have correctly understood Dr. Bowen's interpretation of the structure of the region—a sheetlike igneous mass, composed of probable gabbro below, then anorthosite, and finally a cover of syenite and granite, the cover full of fragments from the Grenville roof, and with a certain amount of disturbance occurring during the freezing of the mass, whereby liquid syenite is brought into lateral contact with solid anorthosite—his argument seems to me to imply, or to require, that this sheet was at least equal in size to the present pre-Cambrian area of northern New York and that anorthosite must everywhere underlie syenite. The field evidence, however, seems to me to

[1] *Bull. Geol. Soc. Am.*, XXV, 243–64.

[2] *Am. Jour. Sci.*, XXXIX, 288–94.

demonstrate that the full girth of the anorthosite intrusion is represented by the dimensions shown on the present maps and that the outlying syenite bodies represent distinct and slightly later intrusions.

Dr. Bowen[1] discusses the "Intimate Relation of Syenite and Anorthosite" and makes the following statement:

> This aspect of the anorthosite, i.e., its intimate connection with the syenite, is emphasized in the area as a whole, where, in spite of fairly good exposures, only one other locality showing the intrusive relation of syenite to anorthosite has been found, but where, on the other hand, types intermediate between the two are rather commonly found.

It is chiefly these two points of his paper which I wish to discuss, since my field experience is quite antagonistic to them. I have myself published several localities where dikes of syenite cut the anorthosite, and on the next page of his paper Bowen quotes W. J. Miller as authority for the statement that dikes of syenite cutting anorthosite occur in the Placid region. My thesis is that the general differentiation *in situ* shown by the anorthosite is into anorthosite-gabbro and gabbro, and not into syenite; that such intermediate rocks as do occur are chiefly intermediate between syenite and gabbro, instead of between syenite and anorthosite; and that the demonstrable source of these latter intermediate rocks in many cases, if not in most or all of them, is assimilative attack of a later intrusion upon an earlier, and is not differentiation *in situ*.

The boundary of the anorthosite is in part along faults. Where unfaulted the anorthosite is always found to grade into anorthosite-gabbro, and this into gabbro as the boundary is approached. This change is depicted upon the Long Lake and the Elizabethtown quadrangle maps and occurs also in all other parts of the region in which I have any acquaintance with the boundary. Daly has interpreted this as a chilled border of the anorthosite, and in my judgment this is not only the most reasonable, but in fact the only satisfactory, explanation that can be made of it.[2] If this be true,

[1] *Op. cit.*, p. 211.

[2] *Igneous Rocks and Their Origin*, p. 240.

it follows of necessity that the anorthosite is a differentiate *in situ* from a gabbro intrusion *and that the chilled border determines for us the original size of the mass* at the depth represented by the present erosion surface—in other words, that this particular anorthosite mass cannot be regarded as spreading out underneath the outlying syenite masses and extending throughout the region. If it be argued that the anorthosite body, while cooling, developed a syenite cover, since removed by erosion, I would state that I think this very probable, and would even go so far as to suggest that the Placid and Keene inliers of syenite may be remnants of this cover. If so, it would be in their vicinity that true transitional rocks between syenite and anorthosite would be most likely to occur. Whether they so originated, or represent plugs of syenite rising through the anorthosite, can be determined only in the field with aid of favorable exposures, if any such exist. But even this gives no aid in explanation of the outlying syenite masses.[1]

The syenite-anorthosite boundary across the Long Lake quadrangle suggests intrusive attack of syenite upon anorthosite for its entire length. Along it the syenite develops a basic border of its own, which I have elsewhere endeavored to show is due to assimilation of gabbro and anorthosite gabbro by the molten syenite.[2] In places the syenite thrusts deep salients into the anorthosite, and an excellent sample may be seen on the Long Lake map, coming down to the Raquette River just north of Raquette Falls. It cuts into the anorthosite body to a depth of two miles, cutting out much of the gabbro and anorthosite-gabbro border, though these appear in full width on both sides of the salient. Within it are several inclusions of anorthosite gabbro, five of which are of sufficient size to be delineated on the map. Each inclusion has an aureole of very basic syenite, grading away imperceptibly into the normal rock. These are remnants of the anorthosite-gabbro border which was there before the syenite salient was thrust in, and which has escaped the utter digestion experienced by the remainder.

[1] It should be noted that the transitional antiperthites described by Bowen are from the Placid region (*op. cit.*, pp. 221–22).

[2] *Bull. Geol. Soc. Am.*, XVIII, 477–92; *Bull. 115, N.Y. State Mus.*, pp. 478–82.

In addition the anorthosite is cut by dikes of syenite in several localities, some of them four or five miles in from the anorthosite border. The field evidence seems clear that the anorthosite had solidified, with a chilled border, and had then been attacked from the side by a mass of molten syenite, which in places cut deeply into it. Along the contact a basic border phase of the syenite was produced, which is not a chilled border *because found only along that part of the syenite boundary which is in contact with the anorthosite*, and hence must be due to the assimilative incorporation of anorthositic material. The product is an intermediate rock, but intermediate between syenite and gabbro rather than between syenite and anorthosite. It differs from the normal syenite chiefly in its large content of ferromagnesian minerals rather than by pronounced difference in the character of the feldspar. It somewhat resembles the gabbro, but ability to distinguish the two is quickly attained in the field.

Dr. Bowen's suggested interpretation of these relations is that disturbance occurred during solidification of the sheet-like mass, after the anorthosite had become practically solid, but while the overlying syenite was still fluid, faulting the one against the other and thus permitting the fluid to laterally attack the solid, giving rise to the intrusive features found in the field. This is a possible cause of such relationships, but it seems to me that the presence of the chilled gabbro border of the anorthosite is fatal to its application in this particular case. That border seems to me to indicate that this is the original size of the anorthosite mass; that it cannot therefore extend westward underneath the bordering syenite; that it cannot possibly underlie the great number of other syenite bodies which range away for distances exceeding 50 miles to the west and south.

The presence of anorthosite outliers in the region somewhat complicates the problem, and might be thought to lend support to Bowen's conception of the structure. The largest of these known to me is that at Rand Hill, Clinton County, which I described years ago. This lies 20 miles distant from the nearest part of the main body, at Keeseville, and seems to me to represent a distinct intrusion, though in all probability an offshoot from the same

parent-mass below ground. The other known outliers are all small, are all composed of anorthosite gabbro, lie within a distance of 10 miles from the anorthosite boundary, and are either demonstrable or probable inclusions in the syenite or else are dikelike or pluglike offshoots from the main mass. So far as I know the evidence, they do not at all require belief in the greater extent of the anorthosite mass underground.

Conclusion.—While, therefore, I am quite in accord with Dr. Bowen in the belief that the gabbro, anorthosite, syenite, and (in part) granite bodies of the Adirondacks are all differentiates from a common parent-magma and are closely akin in age, I do not believe that the present surface exposures can be successfully explained as constituting one great igneous body. The anorthosite mass arose to its present position as a gabbro magma, developed a chilled border, differentiated with production of anorthosite and quite possibly overlying syenite, and solidified. The overlying syenite has since been eroded away, except for the possibility that the Placid and Keene inliers may represent portions of it. In so far I can follow Bowen without trouble. But to account for the outlying syenite and granite bodies away from the anorthosite I think that we must resort to the conception of at least one other body of magma, probably of several others, which went through a similar differentiation well below the present surface and from whose upper parts bodies of molten syenite were pushed upward. Some of these came up along the margins of the solidified anorthosite mass while it was still hot and produced the contact relations which we find today.

It is not safe to say, at the present time, that the floor of the entire Adirondack region is constituted of representatives of this one igneous group. It is quite true that the Grenville remnants in the region always rest on igneous rocks which bear an intrusive relation to them. But in my view there are considerable masses of orthogneiss present much older than the rocks of the anorthosite-syenite group; in places the Grenville rests on these, and it is not at all certain that they rest on the younger intrusives; and in many parts of the region these rocks border the anorthosite, as, for example, along Cold River on the Long Lake quadrangle. The

conception of a cylinder of syenite enfolding anorthosite is therefore neither a necessary nor a true one; rather, there are a number of separate syenite masses.

ADIRONDACK INTRUSIVES

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In his paper on the "Structure of the Anorthosite Body in the Adirondacks" Professor Cushing offers some objections to the interpretation of Adirondack igneous geology that was given by me in the paper "The Problem of the Anorthosites," and he has kindly asked me to comment upon his objections. It naturally gives me considerable satisfaction that an investigator with Professor Cushing's broad experience of Adirondack geology should accept the more important and vital aspects of my interpretation of the genesis of Adirondack igneous types. I therefore find myself disinclined to object very vigorously to his remarks on features of Adirondack structure concerning which he finds it necessary to disagree with me. This is especially true since it would be presumptuous on my part to differ from him on any point involving actual knowledge of field facts. Nevertheless, there seem to be certain questions of interpretation on which there is room for alternative views.

The common, basic border phase of the anorthosite Professor Cushing considers fatal to the idea of the extension of that rock type laterally as a sheetlike mass beyond the limits of its present exposure. He accepts Daly's interpretation of this border phase as a chilled portion and considers that this phase must be the outer limit of the anorthosite. I, too, accept Daly's interpretation of the basic border, but consider that it is not necessarily an outer limit; it may be an upper limit, or rather a former upper limit. It may therefore represent a chilled upper portion of a laccolithic mass extending far beyond the limits of its present exposure.

It is perhaps necessary to go into this matter in greater detail, and, in order that this may be done, mention will first be made of

a much simpler example of the same phenomenon. In the Palisade diabase of New Jersey gravitative differentiation has taken place with the result that there has been formed in the lower layers an olivine-rich diabase and in the upper layers more acidic types, in local patches verging upon granite. At the upper border, however, a more basic phase occurs which contains a small amount of olivine and represents the original magma quickly chilled and undifferentiated. In this body of moderate dimensions all the differentiates have remained in position, except that the acidic phase may be injected occasionally into the more basic varieties as aplitic dikes. When this occurs, the acidic phase has been noted to exert a particularly strong corrosive or recrystallizing action on the basic phase.

While the differentiates are of other types in the case of the Adirondack complex, I believe that in a broad way the relations are substantially the same, the principal complicating circumstance being the prominence of reintrusion of the later liquid, the syenite. The gabbro border phase I believe, with Daly and Cushing, to be a chilled border, and, while this matter was not discussed in connection with the Adirondacks, mention was made of such chilled phases on page 213. In an undisturbed mass the syenite would everywhere lie immediately below this basic phase if the mass had also a very regular contact. However—and this brings us to another of Professor Cushing's objections—if the mass had an irregular upper contact, the syenite need be present only in the re-entrants of the roof and need not therefore form a continuous border about the anorthosite. Add to this the fact that the syenite has been disturbed and re-intrusion has occurred, and I think that this fact will become still more obvious. It must be confessed that Professor Cushing was perhaps justified in considering a continuous syenite body a necessary consequence of my hypothesis on account of the diagrams that were offered in illustration of the conception. But these were intended to represent in a diagrammatic way the conditions under which the various types were generated, and not to give a picture, except in a generalized way, of the actual distribution of types in the Adirondacks at present. It is recognized that reintrusion of the syenite occurred, resulting in satellitic bodies

at higher horizons in the Grenville, though much of it remained substantially where generated—enough, perhaps, to justify the statement that the Adirondack complex is "*essentially* a sheetlike mass with syenite overlying anorthosite." Whether distant syenite masses are to be regarded as related to the anorthosite I cannot say.

As a consequence of reintrusion, invasion of the anorthosite by syenite, in so far as this occurs, is especially likely to be true of the basic border phase, the anorthosite-gabbro or gabbro, and, after the manner of the acidic phases in the Palisade intrusive, it may be expected that the syenite will exert a strong corrosive or resorbing action on these basic differentiates, such as that described by Professor Cushing from Long Lake. While, therefore, the syenite would be pushed up from below into and beyond the basic phase of the anorthosite, it is considered that the syenite came into being at a higher level than the anorthosite proper. This is not inconsistent with the occasional occurrence of dikes of syenite in the anorthosite, for a splitting of the solidified anorthosite would permit the formation of such dikes from an overlying liquid syenite as readily as from a deeper-seated mass. Professor Cushing is able to bring into court more examples of these dikes than I had supposed were known, but I think that it must be admitted that in much of the quadrangle work the syenite is considered later than the anorthosite solely on the basis of his findings in the Long Lake quadrangle. This might be considered as due to failure of exposure, but in the same areas there is no lack of evidence of the invasion of the Grenville by syenite. I consider it likely, therefore, that the syenite does not invade the anorthosite in exactly the same way, but is largely transitional into it, although, being of somewhat later consolidation, it may send dikes into the anorthosite on occasion. My observations are admittedly limited, but I do not think that the intermediate types to be seen at Lake Placid are formed by interaction of the two types, an action of which Professor Cushing finds abundant evidence at Long Lake. The Placid types are quite definitely intermediate between syenite and anorthosite, not between syenite and gabbro, as are Cushing's reaction types.

In conclusion, I would state that, while Professor Cushing has raised legitimate objections and there is certainly room for difference

of opinion, it still seems to me to be advisable to keep an open mind on the possibility that the syenite and anorthosite occur "*substantially* as layers with the syenite above." It is especially desirable in view of the fact, recognized by Professor Cushing, that the anorthosite occurs in the more deeply eroded portions and the syenite principally at higher horizons, an arrangement not easily reconciled with the opinion that the syenite pushes up into the anorthosite from below.

ADIRONDACK INTRUSIVES

H. P. CUSHING

I am greatly indebted to Dr. Bowen for his additional contribution to this discussion. I take the liberty of considering briefly the points he brings out.

He suggests that the chilled gabbro border of the anorthosite is not a lateral border but a remnant of an upper one. It is very difficult for me clearly to visualize the structure of the region on this view. It is, roughly, about 100 miles across the mid-Adirondack region from east to west, and, again roughly, the easterly half of this distance is occupied by pretty clean anorthosite, and the westerly half contains a great number of syenite bodies and no anorthosite at all. The chilled gabbro border is about midway of the region. If it is a chilled upper portion of a laccolith, consisting of pyroxenite and gabbro below, then anorthosite, then syenite, and, finally, the chilled gabbro roof, since tilted so that the present erosion surface cuts it at a considerable angle, it is necessary to conceive that this chilled upper surface passes below ground in the westerly direction and into the air to the east. Under such a view the present-day syenite masses of the west must have broken through this cover to reach their present position, and there is no particular difficulty in imagining that they did so. But under this view it seems to me necessary that we should also find syenite to the east of the chilled border and close to it—that syenite which formed as a differentiate in the upper part of the chamber, underneath the chilled upper surface. Even if the upper part was very

irregular, as Bowen suggests, so that the syenite differentiate was in separate masses instead of in a continuous sheet, there should still remain considerable masses of syenite within the chilled border and underlying it, if this border was an upper instead of a lateral one. We should find gabbro passing into syenite and this into anorthosite. I know of no such syenite masses within the gabbro border anywhere in the region; and to explain their absence we should be, it seems to me, forced to the conclusion that, owing to disturbance during a late stage of consolidation, every particle of this syenite differentiate in the upper part of the body was forced out through the roof to higher levels, letting the chilled gabbro down upon the anorthosite. This is perhaps possible, but certainly very unlikely, and, moreover, it would leave unexplained the usual slow and even gradation from border gabbro into anorthosite gabbro and of this into anorthosite as we recede from the border—a feature which seems to me convincingly to suggest a lateral border rather than an upper one.

In the Palisade sheet, utilized as an illustration by Bowen, the acidic types lie directly underneath the upper chilled border. In the Adirondacks they lie without and above rather than within and below this border, as they should do on the sheet conception. None of the outlying masses of syenite known to me show any sign of a chilled border of gabbro as if they were upper parts of a single large body. They all seem rather of the type of injections upward from some large mass of magma below. It is to be understood that I am not objecting to the laccolithic conception, but to the conception of a single laccolith occupying the entire region. If we regard the anorthosite mass as a single mass, its margins shown by the chilled border, attacked shortly after its formation by masses of syenite magma, which arose from one or more separate and deeper bodies to the west and which came up along the margin of the anorthosite, not through it, we obtain an explanation of the abrupt transition from anorthosite to syenite territory which obtains in the region and we are free from the difficulties which have just been discussed.

Dr. Bowen's contention that the present-day ideas in regard to the time relationship between syenite and anorthosite are chiefly

due to my observations on the Long Lake quadrangle is correct, but needs some comment in order not to be misleading. The anorthosite district is rugged, wooded, and difficult. Very little of it has been mapped in detail on quadrangle maps. Moreover, the marginal types are weaker and less likely to be well exposed. It is as yet unsafe to argue that the Long Lake phenomena are exceptional because they have not been shown elsewhere.

I regret that Dr. Bowen did not discuss my suggested explanation of the Placid syenite inlier as a remnant of the overlying syenite differentiate of the anorthosite. It is there that he found his rocks transitional between syenite and anorthosite, and it is there that they would be expected, if the inlier is such a remnant. These rocks are not on the border, but are within the mass. If a chilled border is lacking between them and the adjacent anorthosite, then the occurrence would seem most easily explained on this theory.

In conclusion, then, the relations shown in the field along the western border of the anorthosite seem to me to indicate that the anorthosite is one body and the syenite masses to the west and south belong to one or more separate and slightly later bodies. While I welcome Dr. Bowen's theory of the formation of the anorthosite and syenite, I can neither agree with, nor see the necessity of, his idea that all these intrusives of the region are parts of one single laccolithic body. As I picture it, they must represent separate upwellings from one or more deeper-seated magmas. The western border of the anorthosite marks the line of division of the region into contrasted halves—anorthosite to the east, separate syenite masses to the west; and the particular syenite masses which happened to adjoin the anorthosite differ in no particular from those more remote, except in the one that they have assimilated some anorthosite at the contact of the two rocks. Nothing is to be gained by assuming that the adjoining masses belong with the anorthosite body and by attempting to make a separation between them and those more remote. Such a separation would be purely arbitrary, whereas the other divisional line is sharp and obvious.

A REVIEW OF THE AMORPHOUS MINERALS

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Mineralogists generally have neglected the study of naturally occurring amorphous substances. None of the modern mineralogical textbooks or treatises give an adequate treatment of the amorphous state or condition. Crystals are treated at great length, but the amorphous state is usually given only a paragraph or two.[1]

The reasons for this neglect on the part of mineralogists are apparent. Crystals, with their great variety of form and physical properties, offer a more attractive field for study. Crystalline material so greatly predominates over amorphous material in the earth's outer shell that it is regarded as typical of the solid state. In selecting material for chemical analysis crystals are selected as far as possible, for crystallization is Nature's great method of producing pure inorganic substances.

While the mineralogist is primarily a crystallographer and while crystallography is left largely in the hands of the mineralogist, we need to be reminded that mineralogy and crystallography are by no means synonymous. Crystallography deals with crystals produced in the laboratory as well as with mineral crystals. Mineralogy deals with all homogeneous, naturally occurring, inorganic substances, whether crystalline or amorphous. The two fields overlap but do not coincide.

In view of the recent advances in colloid chemistry, the mineralogist can no longer be excused for his neglect of the study of the amorphous state. Although the science of colloid chemistry has been developed largely by chemists, Breithaupt, one of the early mineralogists and perhaps the greatest of the old natural-history

[1] Knop, however, in his *System der Anorganographie* (Leipzig, 1876), and Doelter, in his *Physikalisch-chemische Mineralogie* ((Leipzig, 1905), both treat the amorphous state at some length.

school of mineralogists, recognized colloids under the name porodine substances as early as 1817.[1] He called attention to the fundamental differences between the crystalline and amorphous conditions and divided amorphous substances into two groups: the hyaline (glasses) and porodine ("guhren" or gels). Breithaupt knew of the researches of Graham before the publication of the latter's discovery of dialysis and stated that his group of "guhren" was identical with the laboratory products of Graham.

The application of colloid chemistry to mineralogy has been pointed out by Cornu and others in a series of papers published in 1909[2], and more recently Marc and Himmelbauer[3] have contributed an excellent summary and bibliography of the whole subject.

CONFUSION OF THE TERMS AMORPHOUS AND COLLOIDAL

While the study of the amorphous condition involves a study of the colloidal or "dispersed" state, the terms amorphous and colloidal are not synonymous. Amorphous is the broader term. Ordinary glasses are amorphous but not colloidal, although some varieties of glass may be colloidal (e.g., opalescent glass). Colloids are microheterogeneous systems made up of two phases, one dispersed through another.

Most of the amorphous minerals are hardened hydrogels. The water present is usually considered to be adsorbed water. It may be adsorbed water when the colloid is first formed (even this fact is doubted by Robertson),[4] but after hardening, the water may be present in solid solution.[5] Hyalite opal, for example, is apparently a microhomogeneous substance, and there is no reason why it may not be looked upon as a true solution of water in silica. Hence it is possible, and even probable, that the mineral hydrogels are not, properly speaking, colloids, but only colloidal in origin.

[1] Cornu, *Zeit. f. Chem. u. Ind. d. Kolloide*, IV (1909), 300–4; Hunt, *Systematic Mineralogy*, New York, 1891, p. 10.

[2] *Ibid.*, IV, 15, 89, 187, 188, 189, 275, 285, 291, 295, 298, 300, 304, 306.

[3] *Fortschritte der Min., Krist., u. Petrog.*, III (1913), 11, 32.

[4] *Zeit. f. Chem. u. Ind. d. Kolloide*, III (1908), 49.

[5] The fluorin content of collophone mentioned later in this paper is an argument in favor of the solid solution theory of hydrogels.

Wolfgang Ostwald says: "The colloid solutions . . . . should always be meant when colloids in general are under discussion,"[1] and also "when we speak of a 'colloid' we nearly always mean one in this condition, in other words, one in the *sol condition*."[2]

Bütschli described the gels as possessing a honeycomb structure, but according to Bachmann[3], this is simply an optical effect. By means of the ultramicroscope the latter proved that the structure of the solid gel of silica is extraordinarily fine and for the most part amicroscopic (i.e., made up of amicrons).

Whether the hardened gels are colloidal or not, we are safe in calling them amorphous.

There is a tendency on the part of some modern mineralogists to use the term colloid, not only for the hydrogel minerals, but also for microcrystalline substances of colloidal origin. The recognition of colloidal structures in the study of minerals, rocks, and ores[4] is important, but the fundamental differences between amorphous and crystalline minerals should not be lost sight of. In the identification of minerals the mineralogist is concerned with amorphous and crystalline substances, and not primarily with colloidal structures. The confusion of the terms colloidal and amorphous is apparent in a number of recent mineralogical papers. For example, Cornu[5] classifies chrysocolla as the "gelform" of dioptase, when, as a matter of fact, chrysocolla is crystalline. Its amorphous equivalent is another mineral recognized in this paper for the first time. The use of the term *metacolloid* proposed by Wherry[6] for microcrystalline substances of colloidal origin will do much to clear up the difficulty. Cornu's term "gelform" is ambiguous, and as an illustration let us take the silica minerals. Opal is listed as the "gelform" of chalcedony by Cornu and chalcedony as a "krystalloidform." But both of the minerals have colloidal

[1] *Handbook of Colloid Chemistry* (Eng. trans. of 3d edition by Fischer, 1915), p. 24.

[2] *Ibid.*, p. 40.

[3] *Zeit. f. anorg. Chemie*, LXXIII (1911), 125.

[4] For a discussion of colloidal structures in ores see Krusch, *Zeit. f. prakt. Geol.*, 21. Jahrgang (1913), 506–13.

[5] *Zeit. f. Chem. u. Ind. d. Kolloide*, IV (1909), 17.

[6] *Jour. Wash. Acad. Sci.*, IV (1914), 112.

characteristics, and if we treat them as Cornu treats chrysocolla they would both be considered as colloidal or "gelforms" of quartz. In the case of silica minerals, for example, ambiguity is avoided if we call opal amorphous silica and chalcedony metacolloidal silica.[1]

CRITERIA FOR THE RECOGNITION OF AMORPHOUS SUBSTANCES

To the mineralogist is committed the task of describing and defining all of the definite, homogeneous, naturally occurring substances, whether they be crystalline or amorphous.

How may amorphous substances be distinguished from crystalline substances? On the face of it this seems to be easy, but, as a matter of fact, the problem is often very difficult. Crystalline substances may be defined as those having discontinuous vectorial properties[2] and amorphous substances as those not having such properties, but the actual determination of whether a given substance has discontinuous vectorial properties or not may be very difficult.

From the standpoint of physical chemistry amorphous solids are liquids. Now, the shape of a liquid unaffected by gravity or other external influence is spherical, and so we often find the hydrogel minerals in spherical, botryoidal, reniform, stalactitic, and mammillary forms. These forms intergrade, so that one is often at a loss to know which term to use. I therefore propose the term *colloform* for the rounded, more or less spherical, forms assumed by colloidal and metacolloidal substances in open spaces. Some crystalline, not merely microcrystalline, minerals, such as smithsonite, also occur in colloform crusts, and it should be emphasized that this term refers only to the shape or form, and not to the condition of the material.

Colloform minerals may be either amorphous or crystalline, while, on the other hand, minerals occurring in euhedral crystals may be amorphous alteration products of original crystals, for example, malacon, which is a pseudomorph after zircon. Yttrotantalite, thorite, allanite, gadolinite, homilite, and yttrocrasite all occur in euhedral tetragonal, orthorhombic, or monoclinic crystals.

[1] Chalcedony may be either a distinct mineral or a variety of quartz.

[2] Friedel, *Leçons de Cristallographie* (Paris, 1911), p. 2.

Yet in many cases the material is optically isotropic and we apparently have the amorphous equivalents of these minerals occurring as pseudomorphs after the original crystalline minerals. The typical structures of crystalline aggregates, such as fibrous, lamellar, etc., do not necessarily indicate crystallinity, for these structures may be remnants of an original crystalline condition, now consisting of amorphous material. Pyrolusite, for example, is probably an amorphous manganese dioxid produced by the dehydration of crystalline manganite, which accounts for its fibrous structure.

In the absence of cleavage and other direct proofs of crystallinity we must rely largely upon optical tests for transparent and translucent minerals. A serious difficulty confronts us here, for isometric crystals, as well as amorphous solids, are optically isotropic, and anhedral isometric crystals without cleavage may be confused with amorphous substances of similar appearance.

Still another difficulty lies in the fact that many amorphous substances are doubly refracting. This is especially true of colloform crusts, and the double refraction here is due to strains set up in the hardening of the gel. The hyalite variety of opal practically always shows double refraction. The birefringence of an amorphous mineral is usually very weak, but in some cases it reaches an appreciable amount. In a specimen of phosphorite from Lassa Island containing both dahllite and collophane the double refraction of colloform bands of amorphous collophane is greater than that of the corresponding crystalline dahllite. Double refraction due to strain can usually be distinguished from the double refraction of optically anisotropic crystalline substances by its lack of uniformity.

For opaque minerals etching experiments are perhaps the most satisfactory tests to try in the absence of evident crystalline structure. Tolman[1] has recently described metacolloidal chalcocite. The determination was made by examining polished surfaces etched by nitric acid with the metallographic microscope.

From the foregoing discussion it is evident that in many cases the scalar properties must be used to distinguish amorphous and crystalline substances, and it should be emphasized that the optical properties are also scalar for isometric crystals.

[1] *Bull. 110 Am. Inst. Min. Eng.*, 1916, p. 410.

Among the scalar properties are specific gravity, specific heat, fusibility, solubility, and also the index of refraction for both isometric crystals and amorphous substances. Now, any one of these properties is somewhat different[1] for an amorphous substance and the corresponding crystalline substance, i.e., one with the same, or approximately the same, chemical composition. The solubility and fusibility are not easy to determine accurately, and this is often true of the specific gravity.

The determination of the index of refraction, and not the presence or absence of double refraction, furnishes the most generally available means of identifying a given amorphous mineral. Irregular grains of garnet in the form of sand, for example, are identified as garnet, not because it proves to be crystalline, but because of the isotropic character, high index of refraction, absence of cleavage, pink color, etc. We know it to be crystalline simply because it is garnet. An amorphous mineral corresponding to garnet would have a lower index of refraction. It might be difficult to prove that such a mineral is amorphous in the first place, but if this fact were once established the mineral could be distinguished from garnet or, more accurately speaking, from one of the members of the garnet group by its index of refraction. The index of refraction, however, is sometimes misleading. For example, lussatete is a fibrous variety of silica probably identical with chalcedony, yet it has the index of refraction of opal. The explanation is that minute fibrous aggregates of chalcedony have gradually crystallized out of an amorphous mass of opal.

Many of the amorphous minerals may be distinguished from their crystalline equivalents by the presence of water, which seems to be almost universally present in the amorphous minerals.

THE GENERALLY RECOGNIZED AMORPHOUS MINERALS

Comparatively few amorphous minerals are recognized in standard works on mineralogy. In Dana's *System of Mineralogy* (6th edition, 1892) with its three appendixes (1904, 1909, 1915), for example, approximately one thousand minerals are given the rank

[1] See Knop, *op. cit.*, p. 8.

of distinct species, and of these only seventeen[1] are listed as amorphous. Some of these are probably synonyms and some are undoubtedly crystalline. Of the amorphous minerals described since the appearance of Dana's *System* none has been given the rank of mineral species in the appendixes of that work.

The principal reason why so few amorphous minerals are listed is because the amorphous equivalents of crystalline minerals, with the single exception of opal, are not recognized as distinct mineral species. We find, for example, crystalline cupric oxid (tenorite) united with amorphous cupric oxid (melaconite). Amorphous limonite is united with its fibrous and crystalline equivalent. Crystalline and amorphous ferric oxid are both included under the name hematite.

ARE AMORPHOUS MINERALS TO BE RECOGNIZED?

The chemical composition of most amorphous minerals is not as definite as that of the average crystalline mineral, but since the discovery of the variability in the composition due to solid solution of such well-crystallized minerals as pyrrhotite and nephelite, we can no longer insist that the term "mineral species" be confined to those of definite chemical composition. Many of the amorphous minerals approach closely in chemical composition the corresponding crystalline mineral, as was first emphasized by Cornu,[2] who called these minerals "pseudo-stöchiolithe." Practically all the amorphous minerals contain water, even if the corresponding crystalline minerals are anhydrous, but this water or the excess water over that present as hydrion or hydroxyl is probably not essential. The myeline from Rochlitz, Saxony, for example, is probably the amorphous equivalent of kaolinite, yet it contains practically the same amount of water.

Some of the amorphous minerals are definite enough to be recognized, though we must, of course, allow more latitude in

[1] These are opal, collophanite, bindheimite, szmikite, deweylite, genthite, garnierite, spadaite, saponite, glauconite, cimolite, montmorillonite, allophane, collyrite, schrötterite, chloropal, and hisingerite.

[2] *Zeit. f. Chem. u. Ind. d. Kolloide*, IV (1909), 15, 89.

chemical composition and physical properties than with crystalline minerals. The physical properties of many of the amorphous minerals can be determined as completely as those of many of the massive non-cleavable isometric minerals, for in the absence of cleavage and crystal form all the available properties for determination are scalar.

Most authorities admit an amorphous mineral to the full rank of species if it has no crystalline equivalent, but discard those with crystalline equivalents. This, I believe, is inconsistent, and it would seem more logical to refuse admittance to an amorphous mineral until its crystalline modification is described. It is also inconsistent to recognize opal and not the other amorphous equivalent of crystallized minerals. Opal is not a definite hydrate of silica, but is silica with dissolved or adsorbed water. Other amorphous minerals also contain dissolved or adsorbed water and bear the same relation to crystalline equivalents that opal does to quartz. As shown by von Weimarn,[1] the colloidal condition is a general property of matter. No one can doubt that the amorphous and crystalline conditions are fundamentally different. Any given substance possesses a different energy content in these two conditions.

If it is admitted that the properties of amorphous minerals are sufficiently distinct, and we admit this when we use such names as opal, pitticite, allophane, etc., we must assign the known amorphous equivalents of crystallized minerals the rank of independent mineral species. The first step in this direction was taken, I believe, by Cornu[2] in 1909. He introduces the names kliachite, stilpnosiderite, gelvariscite, gelfischerite, geldiadochite, gelpyrophyllite, etc., as names of the amorphous equivalents of hydrargillite, limonite, variscite, fischerite, diadochite, and pyrophyllite, respectively. This, in my opinion, is one of the important advances in systematic mineralogy. Although sound from the standpoint of physical chemistry, this principle has not been generally adopted. We are conservative, and even desirable changes are slow in adoption, but it seems strange that such names as cliachite or kliachite are not

[1] *Zur Lehre von den Züstanden der Materie* (Leipzig, 1914).

[2] *Zeit. f. Chem. u. Ind. d. Kolloide*, IV (1909), 15.

adopted when so many new names of mere varieties or mixtures of older minerals[1] are apparently welcomed.

NAMES FOR AMORPHOUS MINERALS

If it be granted that amorphous minerals deserve recognition, then names of some kind are necessary. Are these to be distinctive names or modifications of the names of the corresponding crystalline minerals? Cornu used the prefix "gel" with the crystalline modification (e.g., gelvariscite, for the amorphous equivalent of variscite). Tućan[2] employed a similar device, except that "gel" came after the root name instead of before it (e.g., hematogelite for colloidal ferric oxid). Wherry[3] proposed that the Greek letter κ (the abbreviation of κολλα) be used as a prefix to the crystalline compound (e.g., κ-limonite for stilpnosiderite).

A serious objection to all these proposals lies in the fact that the amorphous mineral is not related to one polymorphous modification any more than to another. Most mineral substances are known in but one crystalline modification, but other modifications may be found in the future, as polymorphism seems to be a general phenomenon of nature.

The name of any crystalline mineral connotes certain crystal forms and physical properties as well as a given chemical composition. It is absurd, then, to speak of amorphous calcite or amorphous aragonite. The proper term to use is amorphous calcium carbonate.

Distinctive names, then, are necessary, or at least advisable, for the amorphous equivalents of crystalline as well as for the other amorphous minerals. As an illustration of the need of distinctive names for amorphous minerals, let me cite the case of variscite. Cornu, in 1909, called its amorphous equivalent gelvariscite, but Schaller has recently described lucinite, a dimorph of variscite.

Few new names are necessary, for varietal and other discarded names may be used. In this paper I have recognized about twenty

[1] See paper by the author, "The Nomenclature of Minerals," *Trans. Am. Phil. Soc.*, LII (1913), 606–15.

[2] *Centralblatt f. Min. Geol. u. Pal.*, 1913, p. 68.

[3] *Ibid.*, pp. 517–18.

of the best-defined amorphous minerals and have found it necessary to introduce but two new names. In the future other new names will be necessary, but their introduction will be gradual. It is not desirable to recognize all amorphous mineral substances, but only those that will stand the test of a critical examination, and usually only those that are found in a number of localities. I would emphasize especially the recognition of those with crystalline equivalents, for then we have a comparison of properties which are especially useful in determination.

SOME OF THE PROMINENT AMORPHOUS MINERALS

I now propose to describe and discuss what seem to be the better established amorphous minerals, with especial emphasis upon those that I have been able to study in more or less detail.

Amorphous carbon (schungite, mineral charcoal).—Graphite is the hexagonal modification of carbon, and the so-called amorphous graphite is probably compact, dense graphite in a fine state of division. Graphitite and graphitoid, according to Weinschenk,[1] are simply varieties of graphite.

Schungite, described by Iostranzeff from near Schunga, Government Olenez, Russia, is an amorphous modification of carbon, for when treated with a mixture of potassium chlorate and nitric acid it is soluble and is not, like graphite, converted into the yellow, scaly substance called graphitic acid.

Amorphous sulfur (sulfurite).—Besides the common orthorhombic, and the rare monoclinic, sulfur found at a few localities amorphous sulfur also probably occurs in nature. Rinne[2] has proposed the name sulfurite for naturally occurring amorphous sulfur. He describes an arsenical variety (arsensulfurite) which occurs as amorphous crusts on andesite.

Xanthochroite $CdS(H_2O)_x$? (greenockite in part).—The cadmium sulfid which occurs as a thin incrustation on sphalerite is amorphous, as has been recognized by Lacroix and by Christomanos. It is usually called greenockite, but the original cadmium sulfid first described from Scotland and found in but few other

[1] *Zeit. f. Kryst. u. Min.*, XXVIII (1897), 291.

[2] *Centralblatt f. Min. Geol. u. Pal.*, 1902, p. 499.

localities is hexagonal. A new name is necessary for amorphous cadmium sulfid and I propose to call it *xanthochroite* (Greek *xanthos*, yellow, *chroa*, color).

This mineral has recently been found near Topaz, Mono County, California, where it occurs as a thin coating on massive magnetite. With the magnetite is associated sphalerite, and the xanthochroite is doubtless a secondary mineral derived from sphalerite. It varies from yellow to orange in color and is almost opaque when examined with the microscope. There is no evidence of crystallization or double refraction. It is soluble in hydrochloric acid and is reprecipitated by hydrogen sulfid. It is immediately darkened by copper sulfate solution, and this will probably distinguish it from crystalline greenockite.

Hydrotroilite. $FeS(H_2O)_x$.—The black slime found in inland seas and in some moist sands and clays is colloidal and amorphous ferrous sulfid. It has been described from Hadishibey Liman in Southern Russia by Sidorenko[1] and the name hydrotroilite given to it. As troilite is a synonym of pyrrhotite, the name is not a very fortunate one, but it has priority.

I am indebted to Mr. G. A. Waring, of the United States Geological Survey, for a black slimy deposit from the Kruzgekampa Spring, 60 miles north of Nome, Alaska. This consists of a black, opaque substance mixed with sand grains and diatoms. The black substance is hydrotroilite. It is soluble in cold hydrochloric acid with the evolution of hydrogen sulfid. The solution gives tests for ferrous iron, and with ammonia a black precipitate is obtained.

Wherry[2] proposes to call the melnikowite of Doss[3] κ-pyrite, but melnikowite is microcrystalline (metacolloidal) FeS_2 and not amorphous. This is a serious objection to Wherry's scheme of nomenclature.

Opal. $SiO_2(H_2O)_x$ (lardite).—Opal is a typical amorphous hydrogel and is unique in that, until Cornu's work in 1909, it was the only amorphous equivalent of a crystallized mineral generally

[1] For reference to original article see *Neues Jahrb. f. Min. Geol. u. Pal.*, II (1902), ref. p. 397.

[2] *Central. f. Min. Geol. u. Pal.*, 1913, p. 518.

[3] *Neues Jahrb.*, Beil. Bd. XXXIII (1912), 689–93.

recognized as a distinct species. The properties of opal are so well known that a description is unnecessary. Attention, however, should be called to the fact that hyalite opal, the purest and most typical form of opal, usually shows double refraction due to strain.

(*Lechateliérite*)?—The amorphous constituent of fulgurites and of some inclusions in volcanic rocks has recently been named lechateliérite by Lacroix.[1] This material approaches silica glass in composition and is also very similar to opal in properties. The only difference between lechateliérite and opal is due to their previous history, but, as Miers says, ". . . . the essential character of a mineral, moreover, is quite independent of its source or previous history."[2] Yet these two substances are so different in occurrence and origin that one feels inclined to consider them as distinctive minerals. Then we are confronted with the question whether we are ever to recognize more than one amorphous mineral for a given crystalline equivalent or not.

Now, lechateliérite is a glass and may be considered along with other natural glasses as a mineraloid (see p. 540) rather than as a mineral proper. As an argument for this, I give the results of my examination of a fulgurite found in the sand dunes along Lake Michigan in Van Buren County, Michigan, and obtained from Ward's Natural Science Establishment. The fulgurite is a hollow tube of glass with small grains of white sand adhering to the exterior surface. The sand grains are quartz and orthoclase. The glass is colorless and perfectly isotropic with an index of refraction of 1.462 ± 0.003. It is fusible on the edges and gives a small amount of water in the closed tube. From these tests it can be seen that the glass is not pure silica, but a glass high in silica. The lechateliérite described by Lacroix is almost pure silica, as its index of refraction is 1.458. Whether a distinctive name is desirable or not, the glass of fulgurites may be considered simply as a mineraloid, which approaches pure silica glass in composition.

Hydrocuprite. $Cu_2O(H_2O)_x$ (hydrocuprite, ziegelite, ziguéline, tile-ore).—Two kinds of cuprous oxid occur in nature: (1) isometric cuprite and (2) amorphous tile-ore, for which the name

[1] *Bull. Soc. Fran. de Min.*, XXXVIII (1915), 182–86.

[2] *Mineralogy*, 1902, p. v.

hydrocuprite may be used. Werner considered *rothkupfererz* and *zeigelerz* as co-ordinate. Beudant used the name ziguéline as a species name for cuprous oxid. Hydrocuprite was described by Genth[1] as an orange-yellow to orange-red, amorphous raglike coating on magnetite from Cornwall. The same substance has been noted by Lacroix on cuprite from Chessy, France, and by Sandberger, mixed with cuprite, from Schapbach, Baden. According to Schaller[2] the supposed vanadium ocher from Lake Superior is hydrocuprite (or possibly cuprite).

I have observed what I consider to be amorphous cuprous oxid in specimens from the Lowell mine, Bisbee, Arizona; the Poderosa mine, Collahuasi, Chile; and an unknown locality. The hydrocuprite occurs as a massive brick-red mineral associated with cuprite. Under the microscope it appears as an orange-colored, almost opaque substance in contrast to the dark-red translucent cuprite. No very satisfactory optical tests can be made on account of the opacity, but in a few spots the orange-colored mineral is isotropic as well as the cuprite.

On account of the optically isotropic character of both of these minerals the closed-tube test may prove useful. Hydrocuprite contains water, but it is not a definite hydrate, as the name implies.

Melaconite. $CuO(H_2O)_x$ (tenorite in part, melanochalcite).—Dana united the crystalline tenorite and amorphous melaconite under the name tenorite, but they should be separated. Crystalline tenorite is a very rare mineral, known only from Vesuvius, Cornwall, and Keweenaw Point, Michigan, but the amorphous melaconite is a fairly common mineral in the oxidized zone of copper mines. It is a black, massive mineral and occasionally occurs in colloform crusts. In fragments it is black and opaque, but is usually translucent brown and isotropic on the thin edges. In addition to cupric oxid and water melaconite also contains silica, the carbonate radical, and often manganese oxid.

Melanochalcite, described by Koenig as a copper salt of silicocarbonic acid, is undoubtedly melaconite. Kraus and Hunt[3]

[1] *Preliminary Report on the Mineralogy of Pennsylvania*, Pennsylvania Second Geol. Surv., 1875, p. 46.

[2] *Am. Jour. Sci.* (4), XXXIX (1915), 404. [3] *Ibid.*, (4), XLI (1915), 211–14.

decide that melanochalcite is a mechanical mixture of tenorite, malachite, and chrysocolla. While the two latter minerals may sometimes be associated with it, homogeneous melaconite free from mechanical impurities also gives tests for the carbonate radical and silica. Melaconite is either an adsorption compound or a solid solution of cupric oxid and water with silica, carbonate radical, and often manganese dioxid.

Hematite. $Fe_2O_3(H_2O)_x$ (hydrohematite, turgite, hematogelite). —Two varieties of ferric oxid are generally recognized, a crystalline one and a massive or earthy-red one. Haüy and Werner respectively considered these as distinct minerals under the names fer oligiste, fer oxydé rouge and eisenglanz, rotheisenstein. They were united by Hausmann, and he has been generally followed by other mineralogists. The red, earthy varieties of ferric oxid, such as the oölitic Clinton ore and the soft hematites from the Mesabi range, are amorphous and should be separated from the crystalline ferric oxid. The amorphous ferric oxid may be distinguished from the crystalline mineral by the fact that it contains a small amount of water.

Turgite is usually considered to be $2Fe_2O_3 \cdot H_2O$, but it is probably not a definite hydrate. Turgite often occurs in colloform crusts. It sometimes shows a fibrous structure, but this is probably because it is a dehydration product of limonite and retains its structure. In fragments turgite is very dark red, sometimes isotropic and sometimes birefringent. The double refraction may be due to strain. Turgite is essentially identical with amorphous hematite.

Specularite, now used as a varietal name by many mining geologists, may be used as a specific name for crystalline ferric oxid, and hematite then may be used exclusively for amorphous ferric oxid.

Limonite. $Fe_4H_6O_9(H_2O)_x(?)$ (stilpnosiderite, melanosiderite, limnite, esmeraldaite, xanthosiderite ?).—Leaving göthite out of consideration, hydrous ferric oxid with a yellow-brown streak occurs in two distinct forms, a crystalline fibrous form and an amorphous massive form. Under the microscope the former appears as crystalline fibers with parallel extinction, and the latter is

optically isotropic and usually structureless. As Cornu suggests, these two forms should have distinctive names. He used limonite for the crystalline mineral and stilpnosiderite for the amorphous one, but in view of the fact that the simpler name limonite is so well established for the common and widely distributed brown hydrated iron ore of surface origin it seems advisable to retain the name limonite for the amorphous mineral. Limonite in this restricted sense has priority over stilpnosiderite, for it was used by Hausmann in 1813, while the name stilpnosiderite was introduced by Ullmann in 1814 and usually has been used as a varietal name for *eisenpecherz*.

A new name is necessary for the crystalline mineral with the composition $Fe_4H_6O_9$, but in view of the fact that the mineral hydroxids of irod are being investigated by the Geophysical Laboratory no suggestion is offered at present.

The melanosiderite of Genth is not an iron silicate, but limonite with dissolved or adsorbed silica. The water content of the amorphous ferric oxids is variable, and so it is probable that xanthosiderite, limnite, and esmeraldaite are not definite hydrates, but are all simply varieties of limonite.

Stibiconite. $Sb_2O_4(H_2O)_x$ (stibianite, stiblith, stibioferrite, volgerite).—The most common alteration product of stibnite is the amorphous mineral stibiconite. It is probably colloidal antimony tetroxid with adsorbed or dissolved water and not a definite hydrate. The existence of crystalline antimony tetroxid is doubtful, for no accurate description of cervantite has ever been made. Tenné and Calderon state that much of the supposed Spanish cervantite is valentinite.

Cliachite. $Al_2O_3(H_2O)_x$ (bauxite in part, wocheinite, sporogelite, alumogel, shanyavskite).—Bauxite should be used as the name of a certain type of rock and not as a mineralogical term. It was so regarded by Dufrenoy, who introduced the name in 1845. He has been followed by Tućan, Tschermak, and Lacroix. Dittler and Doelter, however, use bauxitite for the rock name.

The principal constituent of bauxite is an amorphous mineral called cliachite (kliachite) by Cornu, who revived the name used by Breithaupt.

The crystalline mineral corresponding to cliachite is hydrargillite or gibbsite. This occurs to a minor extent in pisolitic bauxite and also in some clays, but in the "granitic type" of bauxite from central Arkansas[1] hydrargillite is the principal mineral.

The composition of bauxite is usually given as $Al_2O_3 \cdot 2H_2O$, but, as in the other amorphous minerals, the water content of cliachite is variable. In the purest of the Georgia bauxites the ratio of Al_2O_3 to H_2O is very close to 1 to 3, according to Watson.[2]

An amorphous mineral from India described by Warth[3] under the name gibbsite has the composition $Al_2O_3 \cdot 3H_2O$ and is probably cliachite.

Shanyavskite, an amorphous mineral with the composition $Al_2O_3 \cdot 4H_2O$, is probably essentially the same as cliachite.

I have examined several specimens of cliachite and have found the index of refraction to be 1.570 ± 0.005.

Pyrolusite. $MnO_2(H_2O)_x$.—Pyrolusite is probably an amorphous manganese dioxid corresponding to crystalline polianite. The fibrous structure is due to the fact that it is pseudomorphous after manganite. It always contains a small amount of water.

Psilomelane. Formula doubtful (wad, lithiophorite, asbolane, lampadite).—Lacroix says that psilomelane is crystalline. There may be crystalline equivalents of psilomelane, such as hollandite and romanéchite, but most specimens of psilomelane show no indication of crystalline structure and are doubtless amorphous. Psilomelane is probably a salt of some manganese acid and not simply an oxid of manganese. Along with water it may contain BaO, CaO, MgO, Fe_2O_3, Al_2O_3, K_2O, Na_2O, Li_2O, CoO, and CuO. A specimen from near Sodaville, Nevada, presented to me by Mr. L. B. Spencer, is said to contain SnO_2 and WO_3.

Collophane. $3Ca_3(PO_4)_2 \cdot Ca(CO_3,F_2)(H_2O)_x$ (apatite in part, collophanite, fluocollophanite, quercyite, nauruite).—The principal constituent of phosphorite or so-called phosphate rock is not massive apatite, but an amorphous substance which is identical with

[1] Mead, *Econ. Geol.*, X (1915), 41.

[2] *Am. Geol.*, XXVIII (1901), 25.

[3] *Mineral. Mag.*, XIII (1902), 172.

the kollophan of Sandberger. Collophane[1] is a calcium carbonophosphate approaching the formula given above. When the mineral was first described, the calcium carbonate present was thought to be an impurity and so was deducted from the analysis. The chemical composition, as with most amorphous minerals, is variable and somewhat uncertain, because it is difficult to distinguish mechanical impurities from essential constituents.

Fluorin is present in some specimens, and Lacroix uses the name fluocolophanite for varieties rich in fluorin. Artini[2] describes an amorphous mineral in the phosphorites of Es Salt, Palestine, which he says is a fluorcollophanite near fluorapatite in composition. I have found that fossil bones consist of the mineral collophane, and Carnot[3] has shown that the fluorin content of fossil bones increases with the geological age of the bones. If there is an amorphous equivalent of fluorapatite, should a distinctive name, such as fluocollophane, be used for it? As more latitude must be allowed in the chemical composition of amorphous minerals than in the crystalline minerals, it hardly seems advisable to use more than one name (collophane) for amorphous equivalents of minerals of the apatite group. The fluorin determination is not an accurate one, and fluorin in analyses of the phosphorites may be due to fluorite or residual apatite.

Collophane is a massive mineral and often has oölitic or concretionary structure. In cavities it appears in colloform crusts and often resembles opal. The color is sometimes white, but is usually yellow, brown, or black, and is probably due to an organic pigment.

Collophane is isotropic in part, but frequently shows double refraction. In a specimen of phosphorite from Lassa Island the double refraction of the colloform collophane is greater than that of the accompanying fibrous dahllite. I have examined specimens

[1] Dana changed kollophan to collophanite, but since the name has not come into general use it is preferable to use the English equivalent of the original, which is a simpler and more euphonious name. Another argument is that collophanite may be confused with colophonite, a variety of garnet.

[2] Abstract in *Zeit. f. Kryst. u. Min.*, LV (1915), 320.

[3] *Ann. de Mines* (9), III (1893), 155.

of fossilized bones consisting of collophane which shows an appreciable amount of double refraction. The double refraction is variable from spot to spot, and the result is a characteristic wavy extinction.

In view of these facts the safest method of distinguishing collophane from dahllite is usually by means of the index of refraction. I have determined the index of refraction of collophane from many localities and have found that it usually varies from 1.57 to about 1.61,[1] while that of dahllite varies from about 1.61 to 1.63. With high magnification dahllite shows a fabrous structure which is lacking in collophane.

Like dahllite, collophane is soluble in hot nitric acid with effervescence, but in the closed tube it gives a great deal of water while dahllite gives little or none.

The quercyite of Lacroiz[2] is collophane and not a mixture of dahllite and collophane. I have examined a specimen of a banded calcium carbonophosphate mineral labeled "Hydroapatite, Marseilles, France," which is identical with Lacroix's quercyite. The doubly refracting layers of my specimen and probably of the specimens figured by Lacroix (*op. cit.*, p. 580) are collophane and not dahllite. In support of this view it may be mentioned that the index of refraction (1.598±0.002 in my specimen, but Lacroix gives 1.608) is too low and the water content (3.2 to 6.0 per cent) too high for dahllite. Double refraction is by no means a proof of crystallinity. Lacroix also mentions the fact that the fibers of quercyite lack the individuality of those of dahllite (and staffelite), which is a good argument in favor of its being collophane.

Monite from Mona Island in the West Indies is also a variety of collophane. It is a white, earthy, massive mineral which, under the microscope, is largely isotropic with small doubly refracting spots. The index of refraction is 1.631±0.001, a little higher than for most specimens of collophane. Monite effervesces vigorously in hot nitric acid, so that the carbonate radical was overlooked in Shepard's analysis. In the closed tube it gives abundant

[1] The fluorcollophanite described by Artini (*loc. cit.*) has an index of refraction of 1.630.

[2] *Mineralogie de la France*, IV (1910), 579.

water. Monite also contains the sulfate radical, but this is not present as gypsum, as Shepard thought, for the mineral is homogeneous except for minute crystals of monetite and colloform crusts of dahllite. The sulfate radical probably replaces part of the carbonate radical. Phosphorites from Idaho and South Carolina also contain the sulfate radical.

Nauruite described by Elschner[1] from the island of Nauru is another synonym of collophane. It is a yellow to brown resinous mineral occurring as agate-like layers in cavities of phosphorite. The formula given is $3Ca_3P_2O_8 - \left\{ \begin{matrix} Ca(OH)_2 \\ CaF_2 \end{matrix} \right\}$. The analyses of the Nauru phosphorites all show calcium carbonate, and specimens of typical nauruite kindly furnished by Mr. Elschner effervesce vigorously in hot nitric acid. Under the microscope the Nauru collophane shows banded spherulitic structure and weak double refraction. The index of refraction is 1.597 ± 0.001, which proves that the mineral is not dahllite in spite of its birefringence. The double refraction is variable and is lost upon heating.

I have examined thin sections of phosphorites or so-called phosphate rocks from Florida, South Carolina, Tennessee, Kentucky, Idaho, Nauru, Fanning Island, Ocean Island, Lassa Island, and Clarendon, New Zealand, and have found amorphous collophane to be the principal constituent of all of them. It is often accompanied by dahllite. It seems strange that so little attention has been paid to these carbonophosphate minerals, for they are important from both the economic and scientific standpoints.

Evansite. $Al_3(OH)_6PO_4 \cdot (H_2O)_x$?—Evansite, a hydrous aluminum phosphate described by Forbes in 1864, is a typical amorphous mineral. It occurs as a colloform incrustation and greatly resembles allophane. The index of refraction determined on a specimen from Zelegnik, Hungary, is 1.483 ± 0.003.

Evansite has recently been described from two American localities (Goldburg, Idaho, and Columbiana, Alabama) by Schaller.[2]

Pitticite. $FeAsO_4 \cdot Fe_2O_3 \cdot (H_2O)_x$?—Pitticite is a dark-brown massive mineral resembling limonite. It is a basic ferric aresenate

[1] *Corallogene Phosphat-Inseln Austral Oceanien und Ihre Produkte* (Lübeck, 1913), p. 54.

[2] *Bull. 490, U.S. Geol. Surv.*, 1911, p. 94.

and often contains the sulfate radical. An artificial colloidal basic ferric arsenate has been described by Holmes and Rundfusz.[1]

I have examined specimens of pitticite from two localities, one on the west side of the South Merced River in Mariposa County, California, and the other at Sioux City, Iowa. At the first locality it is an oxidation product of arsenopyrite and at the second it occurs with limonite and aragonite.

Pitchblende $UO_2,UO_3,(H_2O)_x$ (Uraninite in part, nasturan).—The colloform or massive pitchblende seems to be the amorphous equivalent of isometric uraninite. Its water content is higher and its nitrogen and rare earth content lower than that of uraninite. It may also be distinguished by its lower specific gravity (6.5 to 8; uraninite is 9 or above).

Uraninite occurs in pegmatites while pitchblende occurs in metalliferous veins with sulfids.

(*Maskelynite*) ?—Maskelynite was first described by Tschermak from the Shergotty (India) meteorite. It is optically isotropic and in composition is very close to a plagioclase with equal molecular percentages of albite and anorthite. As the index of refraction is almost exactly the same as that of an artificial glass[2] of the composition Ab_1An_1, it is probably the amorphous equivalent of plagioclase (not necessarily a fused plagioclase) and not an isometric mineral.

Maskelynite is on the same footing as lechateliérite. They are the only glasses which have been regarded as minerals within recent years. They may be disposed of by considering them mineraloids rather than as definite minerals.

Malacon. $ZrSiO_4(H_2O)_x$? (cyrtolite, auerbachite, oerstedite, ostranite).—Malacon is the name given to a mineral from Hitterö, Norway, which has the form of zircon, but is softer and contains water. It is undoubtedly an alteration product and in all probability the amorphous equivalent of zircon. It deserves recognition as a distinct mineral, and Lacroix so regards it.

Malacon may be distinguished from zircon, not only by its isotropic character and water content, but also by its inferior hardness and specific gravity and its lower index refraction ($n = 1.826$

[1] *Jour. Am. Chem. Soc.*, XXXVIII (October, 1916), 1970.

[2] Larsen, *Am. Jour. Sci.* (4), XXVIII (1909), 267.

Larsen). The other minerals mentioned above (cyrtolite, etc.) are probably synonyms of malacon.

Halloysite. $H_4Al_2Si_2O_9(H_2O)_x$ (myeline, indianaite, clayite, bole in part, kaolin in part).—It is generally recognized that some of the clays consist in whole or in part of amorphous aluminum silicates. Mellor[1] has proposed the name clayite for the amorphous constituent, but fortunately halloysite has priority.

Halloysite may be regarded as the amorphous equivalent of crystalline kaolinite, for it has the formula $H_4Al_2Si_2O_9+_x(H_2O.)$ In LeChatelier's experiments on halloysite the water given off below 250° C. varied within wide limits, while the water given off above this temperature was fairly constant and corresponded to that of kaolinite.

Myeline is an indurated clay from Rochlitz, Saxony, which is almost identical with kaolinite in chemical composition. I have examined a specimen from the type locality and find it to be essentially amorphous (there are patches of micro-crystalline material) with an index of refraction of 1.556 ± 0.001. Gagel[2] has described a non-crystalline myeline-like substance which occurs as an alteration product of trachydolerite at Canical, Madeira.

I have examined indianaite from St. Lawrence County, Indiana, which the published analyses show is a very pure halloysite, and find it to be an amorphous mineral with an index of refraction of 1.538 ± 0.002, which is less than that of kaolinite ($n = 1.567 - 1.561$).

A clay from Morton, Minnesota, with imperfect pisolitic structure consists largely of an amorphous substance with an index of refraction of 1.557 ± 0.003, and hence may be referred to halloysite. This clay also contains some hydrargillite.

I have examined "kaolin" from Broken Hill, New South Wales, and find it to be amorphous with $n = 1.548 \pm 0.002$. This must be halloysite.

The "isotropic kaolinite-like mineral" described by Larsen and Wells[3] from Wagon Wheel Gap, Colorado, has an index of refraction

[1] *Trans. Eng. Cer. Soc.*, VIII (1908).

[2] *Central. f. Min., Geol., u. Pal.*, 1910, p. 225.

[3] *Proc. Nat. Acad. Sci.*, II (1916), 364.

of 1.557 and a water content of 15.5 per cent, and hence should be referrred to halloysite.

Helmhacker[1] describes halloysite with a small botryoidal surface from Banat, Hungary. The Rochlitz myeline also shows colloform crusts in cavities.

From the available evidence it seems clear that halloysite is the amorphous equivalent of kaolinite. The recognition of this may help in a clearer understanding of the constitution of clays. The determination of the index refraction, which varies from 1.538 to 1.557, is probably a safer means of distinguishing halloysite from kaolinite than the absence of double refraction. The presence of aluminum hydrate in solid solution may, however, modify the index of refraction.

Allophane. $Al_2SiO_5(H_2O)_x$ (carolathine).—Allophane has long been recognized as one of the typical amorphous minerals. Its colloform shape, optical isotropism, and absence of cleavage and structure leave no doubt as to its amorphous character. The index of refraction of a specimen from Bedford, Indiana, is 1.473 ± 0.003.

Whether schrötterite and collyrite should be considered synonyms of allophane is open to question.

Stevensite. $H_2Mg_3(SiO_3)_4 \cdot (H_2O)_x$ (talc in part, lucianite?).—An alteration product of pectolite found at several localities in New Jersey is probably the amorphous equivalent of crystalline talc. This substance was first described by Leeds[2] who used stevensite as a name for talc pseudomorphous after pectolite. Glenn[3] has recently studied this mineral, and his work proves that it should be considered a distinct mineral. Wherry made a microscopic examination and shows that it is isotropic with an index of refraction of about 1.50. Stevensite is also distinguished from talc by its lower specific gravity and higher water content.

Stevensite is probably not a monohydrate of talc, as Glenn suggests, but the water content is evidently variable and reaches over 19 per cent in the clay mentioned in the next paragraph.

[1] *Min. u. petr. Mitth.*, II (1879), 232.

[2] *Am. Jour. Sci.* (3), VI (1873), 22–23.

[3] *American Mineralogist*, I (1916), 44–46.

Hilgard[1] has recently described, from a locality near the City of Mexico, a peculiar clay which consists largely of a hydrous magnesium silicate. This substance was named lucianite, but as it is a colloidal substance with specific gravity of 2.25 and is soluble in hydrochloric acid it is probably a synonym of stevensite.

Cornuite. $m\mathrm{CuO}\cdot n\mathrm{SiO_2}\cdot(\mathrm{H_2O})_x$ (chrysocolla in part).—In specimens of chrysocolla from a number of localities I have noted a glassy, green or bluish-green copper silicate which is the amorphous equivalent of chrysocolla. To this newly recognized mineral I wish to apply the name *cornuite* in honor of the late Dr. Felix Cornu, of Leoben, Austria, who was practically the first mineralogist to make a sharp distinction between crystalline minerals and their amorphous equivalents.

I have found this mineral on specimens from Globe, Arizona; Bisbee, Arizona; Ludwig, Nevada; Copper Mountain, Alaska, and Collahuasi, Chile. It is usually optically isotropic with n varying from 1.525 to 1.549, but sometimes has irregular, weak double refraction and wavy extinction. It is associated with crystalline chrysocolla and often appears in colloform bands within layers of colloform chrysocolla. It is more readily soluble in hydrochloric acid than chrysocolla and also somewhat softer.

The best specimens of cornuite in my possession are from the mine of the Alaska Consolidated Mining and Smelting Company at Copper Mountain, Prince of Wales Island, Alaska. It occurs as a beautiful bluish-green (Ridgway 42k), transparent, glassy, somewhat banded crust about 1 cm. thick associated with chrysocolla. The index of refraction is 1.549 ± 0.001. I am indebted to my collegue, Dr. G. S. Bohart of the chemistry department, for the following analysis of the Copper Mountain cornuite:

		Ratios
CuO	= 42.61	0.537
Al_2O_3	= 0.31	0.004
SiO_2	= 34.13	0.566
H_2O	= 23.11	1.284

These figures are each the average of two closely agreeing values made upon carefully selected material free from the associated

[1] *Proc. Nat. Acad. Sci.*, II (1916), 8–12.

chrysocolla and all other impurities. The ratios seem to show an excess of both silica and water over that required for the usually accepted empirical formula (H_4CuSiO_5) for chrysocolla, which probably indicates that cornuite is a solid solution of cupric oxid, silica, and water.

Probert[1] describes a "jelly of the most beautiful shades of blue and green" with the following composition: $CuO = 47.46$; $SiO_2 = 21.20$; $H_2O = 28.05$; $CaO = 1.39$; $Al_2O_3 = tr.$, from the 200-foot level of Ray Central mine at Ray, Arizona. Here we evidently have cornuite in process of formation.

Chrysocolla is sometimes considered to be an amorphous mineral, but while chrysocolla shows colloidal structures it is microcrystalline (metacolloid), and recently Umpleby[2] has described crystallized chrysocolla from Mackay, Idaho, the indices of refraction of which are $n_y = 1.57$ and $n_a = 1.46$.

OTHER POSSIBLE VALID AMORPHOUS MINERAL SPECIES

The twenty-three amorphous minerals described in this paper are all believed to be well-established mineral species. Practically all of them are known from several localities and some of them are very common and widely distributed minerals. Although their properties vary somewhat, these minerals are fairly definite and can be recognized by careful work.

There are, however, as many more amorphous minerals which have been described or named, and some of these it may be possible to establish by study of suitable material. I have attempted to enumerate here some of the probable amorphous minerals.

Metastibnite, amorphous Sb_2S_3.
Jordisite, colloidal MoS_2.
Patronite, vanadium sulfid.
Ostwaldite (Buttermilcherz), colloidal AgCl.
Ehrenwerthite, colloidal $Fe_2O_3 \cdot H_2O$.
Amorphous equivalent of fischerite.
Schadeite, amorphous equivalent of plumbogumnite.
Palmerite, hydrous aluminum potassium phosphate.
Yukonite, hydrous calcium iron arsenate.

[1] *Min. and Sci. Press*, CXII (1916), 898.

[2] *Jour. Wash. Acad. Sci.*, IV (1914), 181.

Gummite, alteration product of uraninite.
Glockerite, hydrous ferric sulfate.
Plumboniobite.
Amorphous equivalent of thorite.
Amorphous equivalent of allanite.
Amorphous equivalent of gadolinite.
Amorphous equivalent of yttrotantalite.
Amorphous equivalent of homilite.
Amorphous equivalent of yttrocrasite.
Amorphous equivalent of pyrophyllite.
Greenalite, hydrous ferrous silicate.
Yttrialite.
Neotocite.
Plombierite.
Geolyte (Bodenzeolith), amorphous equivalent of zeolites.
Pochite.

MINERALOIDS (HYDROCARBONS AND GLASSES)

In addition to the foregoing definite amorphous minerals there are several other classes of naturally occurring amorphous substances. I refer to the hydrocarbons and glasses. Shall they be considered as minerals or not? The answer depends upon our definition of the term mineral or mineral species. A mineral (species) is usually defined as a naturally occurring homogeneous substance of definite chemical composition. By common consent the term is limited to the naturally occurring substances, although the specific mineral name is often used for the corresponding artificial substance. No objection can be raised if the word synthetic or artificial is prefixed to the mineral name. In view of the discovery of solid solutions of a kind different from isomorphous mixtures in minerals, the definition given above must be modified so as to read "of more or less definite chemical composition," as suggested by Wherry.[1]

In the case of the hydrocarbons the principal objection against considering them minerals is on account of their organic character. While directly or indirectly the result of organic growth, they are on a somewhat different footing from ordinary plant products. They occur with other minerals in sedimentary rocks and are, in

[1] *Ibid.*, pp. 111–14.

fact, fossil resins and fossil fuels. They are collected and studied by geologists.

The hydrocarbons are by some mineralogists given full rank as minerals, by others omitted entirely, by still others treated in an appendix to minerals. The latter procedure seems to be the safest plan, for they are organic substances, and the typical minerals are certainly inorganic, yet on the other hand they deserve some recognition by the mineralogist. The mineralogist is often called upon to identify them, and they should be described from a mineralogical standpoint.

For these reasons I think the hydrocarbons may be included under Niedzwiedzki's term *mineraloid*.[1] As Niedzwiedzki used this term for all naturally occurring amorphous substances, this changes somewhat the original definition of mineraloid. Such substances as opal, cliachite, limonite, collophane, halloysite, etc., are definite enough to be called minerals even though they are amorphous. The term "mineraloid" seems appropriate for the less definite mineral-like substances.

And in the same category I would also place the natural glasses. As far as I know, glass is not given a place in any modern mineralogical treatise, although the older mineralogists described tachylyte and hyalomelane as mineral species. It is, however, included in some of the determinative tables of the rock-forming minerals found in textbooks on petrography, and for the same reason that it is included in these tables it may be treated as a mineraloid. Natural glass is a homogeneous substance to be identified the same as minerals in general.

Natural glass is, of course, varied in composition in comparison with the various types of igneous rocks, yet the average obsidian is probably not much more varied than some of the amorphous minerals. While glass is scarcely entitled to recognition as a mineral, there are arguments in favor of classifying it as a mineraloid. It may well receive a place in the appendixes of our books on mineralogy. This will call attention to its properties and will aid in its identification, which otherwise might be difficult for a beginner who had studied mineralogy but not petrography.

[1] *Centralblatt f. Min., Geol., u. Pal.*, 1909, pp. 661–63.

Glass, like amorphous substances in general, is in part optically isotropic and in part birefringent. The birefringence is shown in many perlites, some varieties of which are veritable Prince Rupert's drops. Besides the chemical composition, the most important property of glass is its refractive index, which, as has been shown by Stark,[1] varies from about 1.485 for "acid" glasses with 75 per cent silica up to 1.67 for "basic" glasses with 40 per cent silica. Obsidian, perlite, pitchstone, etc., are petrographic terms, but glass as a whole may be treated as a mineraloid from the mineralogical standpoint. Lechateliérite and maskelynite are glasses which are fairly definite in chemical composition.

SUMMARY

Some of the naturally occurring amorphous substances are definite enough to be recognized as mineral species.

The amorphous equivalents of crystalline minerals should be treated as distinctive minerals and should have distinctive names.

About twenty of the more prominent and well-defined amorphous minerals are described and discussed. Most of these minerals are the amorphous equivalents of crystalline minerals.

New names are given to amorphous cadmium sulfid (xanthochroite) and amorphous copper silicate (cornuite) which correspond to sphalerite, greenockite, and chrysocolla respectively.

Arguments are advanced for treating the natural hydrocarbons and natural glasses as mineraloids.

[1] *Min. u. Petr. Mitth.*, XXIII (1904), 536–50.

THE CHAMPLAIN SEA IN THE LAKE ONTARIO BASIN

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INTRODUCTION

The retreating front of the Labradorian ice sheet late in the Wisconsin glacial stage rested for a time against the northwestern slopes of the Adirondack Mountains. Between the ice front in the upper St. Lawrence Valley and the southern rim of the Ontario basin in New York state, the waters of Lake Iroquois were ponded. The history of this lake, with its outlet down the Mohawk Valley past Rome, New York, has been deciphered by Fairchild, Taylor, Spencer, Coleman, and others. Further withdrawal of the ice margin permitted the escape of the Iroquois waters through "Covey Gulf," southwest of the summit of Covey Hill, the northernmost hill on the west flanks of the Adirondacks, a mile north of the international boundary. The altitude of the Covey outlet at the present time is about 1,000 feet, while that of the Rome outlet is 460 feet, but, according to Fairchild,[1] the altitudes of the two outlets during Iroquois time were very similar, "if not practically identical" (see Fig. 1).

North from Covey Hill the land drops rapidly away to the broad, low valley of the St. Lawrence. As soon, therefore, as the edge of the ice sheet had withdrawn a mile or two farther northward, Lake Iroquois was drained. The water in the Ontario basin and the St. Lawrence Valley rapidly fell to sea-level, for the land stood at a much lower altitude then than now. Differential uplift of the Great Lakes region had commenced long before the extinction of Lake Iroquois, and it is commonly held that the Champlain Sea was then at its maximum extent. It has been more or less unconsciously assumed that the history of these sea-level waters in the upper St. Lawrence Valley was simply a slow but progressive

[1] H. L. Fairchild, "Pleistocene Uplift of New York," *Geol. Soc. Amer. Bull.*, XXVII (1916), 235–62.

withdrawal from the maximum of submergence to the present maximum of emergence. Data now available, however, lead to the conclusions that, when the ice barrier was removed from the St.

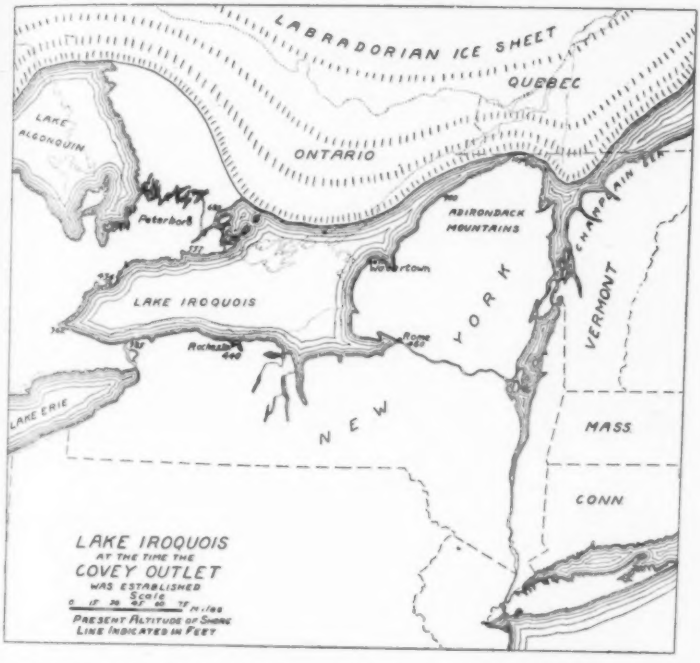

FIG. 1.—A late stage in the history of Lake Iroquois. Lake Algonquin, a portion of which is shown in the Georgian Bay region, overflows through the Fenelon Falls outlet east of Kirkfield, Ontario, and Algonquin River carries its waters to the Rice Lake embayment of Lake Iroquois. The Niagara River outflow from Lake Erie also contributes to Lake Iroquois, which is indicated in its two-outlet stage. Part of its water spills into the Mohawk Valley near Rome, New York, and part falls over the cliff at Covey Gulf, Quebec, into the marine embayment in Champlain Valley. St. Lawrence and Ottawa rivers and parts of the present Great Lakes are indicated by dotted lines. Pleistocene geography based largely upon the work of Fairchild, Coleman, Johnston, and Taylor.

Lawrence Valley north of Covey Hill, the level of the Champlain Sea was far below its maximum height, and that the strand line moved gradually up the valley of the St. Lawrence River and its

tributaries to the position of greatest submergence (Fig. 2) before it began to withdraw toward its present location.

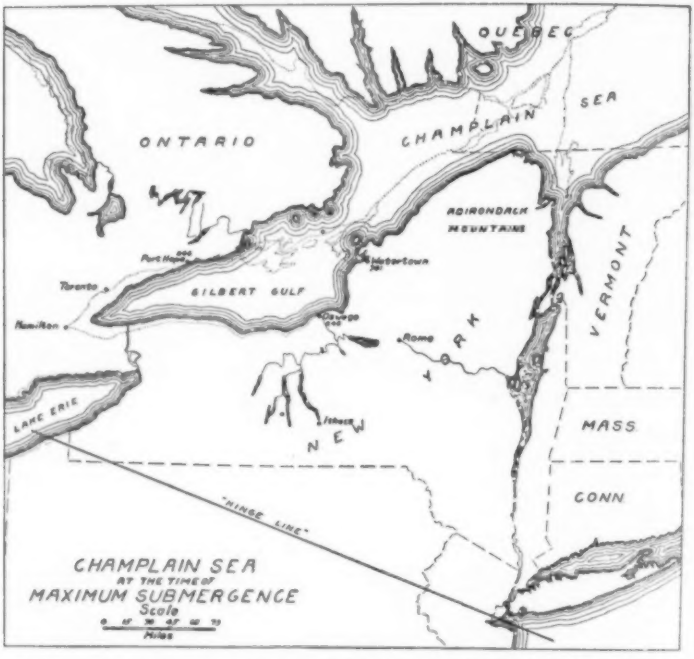

FIG. 2.—The geography of the Ontario-St. Lawrence Valley at the close of Pleistocene time. Champlain Sea is at its maximum extent. Lake Algonquin has been replaced by the Nipissing Great Lakes, which overflow northward down Mattawa and Ottawa rivers. Trent River is a comparatively small stream heading in the Trent chain of lakes and emptying into Gilbert Gulf above Trenton, Ontario. Paleogeography of New York state after Fairchild. Boundaries in Ontario and Quebec generalized and only approximately correct because of scarcity of exact data.

EVIDENCE OF A PROGRESSIVE MARINE SUBMERGENCE OF THE ONTARIO BASIN

Napanee Valley.[1]—Napanee River is one of the many southwesterly flowing streams tributary to Lake Ontario along its

[1] I am indebted to N. B. Davis, of the Department of Mines, Ottawa, for directing my attention to the surficial deposits in Napanee Valley as well as for valuable suggestions made in the field in September, 1916.

northern shore. The river heads in a chain of little lakes which dot the surface of the pre-Cambrian rocks in the central part of Frontenac County, 25 miles north of the east end of Lake Ontario. The lowest of the small lakes is Lake Napanee, 446 feet above sea-level. Thence the river flows across the nearly flat-lying Ordovician limestones which overlap the pre-Cambrian complex, past the towns of Yarker and Napanee to the Bay of Quinte on Lake Ontario (see Fig. 3). From Lake Napanee to Lake Ontario the length of the river is about 24 miles, and its total fall is 200 feet. Throughout this portion of its course Napanee River occupies a pre-Wisconsin youthful valley cut in the limestone cuesta and consequent upon its slope. The valley floor is 75–125 feet below the intervalley upland surface and is bounded by abrupt limestone scarps. Near Yarker the valley walls are scarcely a quarter of a mile apart, but toward Napanee they diverge gradually to a distance of a mile and a half.

The upland surface on either side of Napanee Valley displays abundant evidence of wave and current action. Bedded clays in many places provide a thin veneer of fertile soil over the barren glaciated limestone surface. Elsewhere, bared rock surfaces are studded with the larger bowlders from glacial drift; all the finer products of the glacial mill have been washed away by currents and waves. No distinctive shore features have as yet been observed along the Napanee Valley to mark the upper limit of wave action, but marine or lacustrine clays are present up to altitudes of at least 450 feet in the vicinity of Yarker. At Inverary, 15 miles due east from Yarker and 11 miles north from Kingston, M. B. Baker and I have definitely located the limit of wave action at elevations between 500 and 510 feet above sea-level.

The region is within the area covered by the ice barrier to which Lake Iroquois owed its existence and could not have been freed from its glacial burden until after the extinction of that lake. The wave and current action is therefore that of Gilbert Gulf, the portion of Champlain Sea which occupied the Ontario basin after removal of the ice dam from the Thousand Island region.

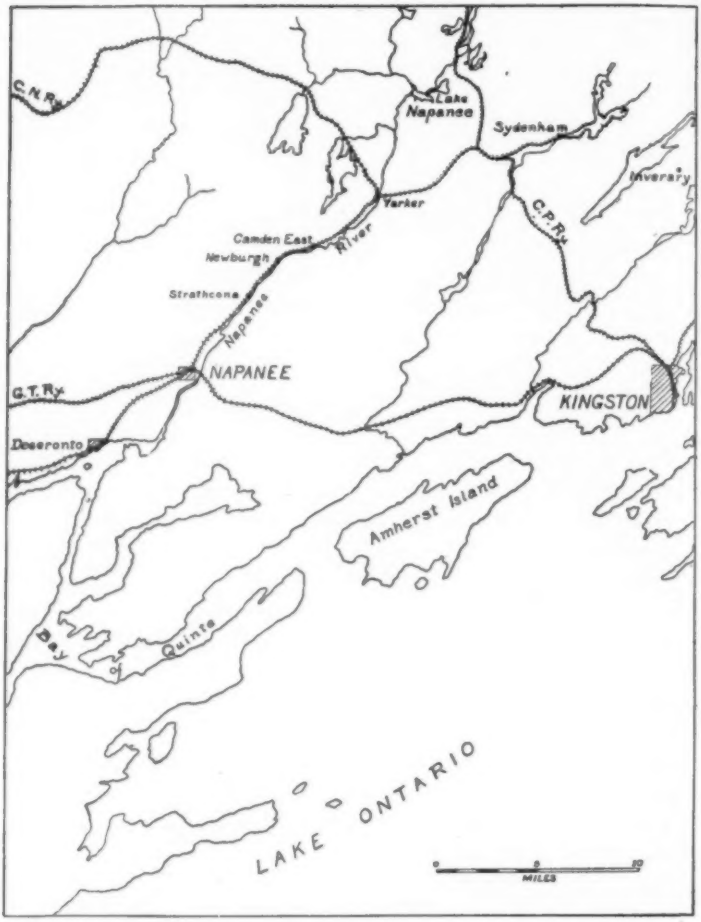

FIG. 3.—Index map of the Kingston-Napanee district, Canada, along the northern shore of the eastern end of Lake Ontario.

Near Ottawa the upper limit of marine submergence has recently been determined[1] to be 690 feet above sea-level. At Belleville the highest marine plane has an altitude of 323 feet.[2] If the gradient is regular between those two localities, the altitude at Yarker would be close to 440 feet. The nearest point on the shore line of Gilbert Gulf in New York, where its features have been mapped by Fairchild, is a small hill $4\frac{1}{2}$ miles southwest from Clayton.[3] This hill is 35 miles S. 70° E. from Yarker; the Gilbert shore encircles it at an elevation slightly above 400 feet. The post-Champlain isobases in this neighborhood run approximately east and west. It is, therefore, quite clear that the Napanee Valley and adjacent uplands were submerged beneath the waters of Gilbert Gulf at least as far northward as Yarker (elevation 425 feet).

That this submergence did not take place when the ice front stood south of the divide at the head of Napanee Valley is clearly indicated by the presence of a valley train of fluvio-glacial gravels within the valley. Remnants of the gravel beds are present at many localities between Yarker and Napanee. Between Newburgh and Strathcona their fluvio-glacial, rather than glacio-lacustrine or glacio-marine, origin is readily apparent. As indicated in Fig. 4, the gravel train has a plane upper surface and its remnants are now distinctly terrace-like. The summit of the valley train is approximately 50 feet above the modern valley flat and has a similar gradient, 8 or 10 feet to the mile. The gravels and sands are irregularly bedded; cross-bedding is common, and assortment according to size of pebbles is very incomplete. Many of the stones are striated or faceted by glacial action. The valley train is in every way a typical sub-aerial fluvio-glacial deposit similar to the comparable outwash gravels of the Fox River Valley in Illinois.

The lowest and most southwesterly remnant of the Napanee valley train is within the city limits of Napanee at an elevation of

[1] W. A. Johnston, "Late Pleistocene Oscillations of Sea-Level in the Ottawa Valley," *Canada Geol. Survey, Mus. Bull. 24*, 1916, p. 5.

[2] F. B. Taylor, "Gilbert Gulf," *U.S. Geol. Survey Mon. 53*, 1915, pp. 445–46; A. P. Coleman, "Marine and Freshwater Beaches of Ontario," *Geol. Soc. Amer. Bull.*, XII (1901), 129–46.

[3] H. L. Fairchild, "Pleistocene Features; Clayton-Lafargeville District," *N.Y. State Mus. Bull. 145*, 1910, pl. 46.

less than 325 feet. In a small gravel pit beside the east abutment of the stone railway bridge the gravels and sands are overlain by bedded clays. Similar bedded clays are present on the floor of the valley eroded into the fluvio-glacial gravel deposits.

At the time of construction of the Napanee valley train the retreating front of the ice sheet had withdrawn less than 10 miles north of Yarker, and the marine plane could not have been over

FIG. 4.—Napanee Valley between Newburgh and Strathcona, Ontario. The cattle in the foreground and the houses and barns in the distance are on the surface of the Napanee valley train. The lower flat in the middle distance is the modern flood-plain of Napanee River. The exposure of fluvio-glacial gravels and sands in the escarpment overlooking the valley flat is in part due to gravel pits and in part to the railroad which parallels the river at the foot of the scarp. Beyond the buildings in the distance, the land rises abruptly to the summit of the limestone cuesta which forms the sky line at the left.

325 feet above present sea-level. Further retreat of the ice cut off the supply of gravel, and dissection of the valley train commenced. Subsequently sea-level waters crept upward and submerged the whole region to at least the 425-foot contour line. In these waters bedded clays accumulated.

Trent Valley.—The anomalous relation between the Trent Valley spillway from Lake Algonquin and the Gilbert Gulf shore features has long been a puzzle to glacialists. The physiographic

features have been described recently by Taylor[1] and Johnston[2] and need not be dwelt upon here. Briefly, Algonquin River carried the overflow from Lake Algonquin to Lake Iroquis and, after its extinction, to Gilbert Gulf. A large delta in the Rice Lake region marks the point at which the river debouched into Lake Iroquois. It is now approximately 620 feet above sea-level. The spillway channel continues down Trent Valley past the Gilbert Gulf shore line (320 feet) to the present level of Lake Ontario (246 feet) near Trenton. The channel below the summit marine plane apparently differs in no way from the portion above that level.

To explain these features by postulating a continuance of the Algonquin River flow until after the lower portion of Trent Valley had been lifted above the level of Champlain Sea is obviously difficult. Neither Taylor nor Johnston is satisfied with that explanation. In the light of the conclusions resulting from the study of Napanee Valley, the difficulties met with in Trent Valley are removed. Algonquin River carried its large volume of water to, and below, the present level of Lake Ontario *before*, rather than *after*, the Trenton neighborhood was submerged beneath sea-level waters. The delta which must have been built at the outlet of the river into Gilbert Gulf is now hidden beneath the lake. Soundings in the Bay of Quinte may some time reveal its hiding-place. By the time the Gilbert strand had crept above the present lake-level retreat of the ice in the Nipissing region had uncovered a new outlet for the upper Great Lakes, and the Lake Algonquin overflow was diverted from the Fenelon Falls outlet.

Confirmatory evidence.—Physiographic features in Napanee and Trent valleys are thus explainable by postulating a positive movement of the strand line in the Ontario basin during the final stages of the waning ice sheet. A similar advance of marine waters in Ottawa Valley has been suggested by Johnston[3] to explain the

[1] F. B. Taylor, "The Pleistocene of Indiana and Michigan and the History of the Great Lakes" (Leverett and Taylor), *U.S. Geol. Survey Mon. 53*, 1915, pp. 445–46.

[2] W. A. Johnston, "The Trent Valley Outlet of Lake Algonquin and the Deformation of the Algonquin Water-Plane in Lake Simcoe District, Ontario," *Canada Geol. Survey Mus. Bull. 23*, 1916.

[3] W. A. Johnston, "Late Pleistocene Oscillations of Sea-Level in the Ottawa Valley," *Canada Geol. Survey Mus. Bull. 24*, 1916.

relations between the fossil-bearing clay zones in the vicinity of Ottawa.

The quaternary deposits near Waterville, Maine, suggest a similar movement of the sea-level there. H. P. Little[1] states that "the main mass of the fluvio-glacial deposits is found in an esker . . . . bordered by marine clays and sands. These overlap the esker and are separated from its gravels by an unconformity considered due to sub-aerial erosion."

CHANGES IN SEA-LEVEL INCIDENT UPON THE WASTING OF THE LABRADORIAN ICE SHEET

The suggestion is an obvious one that the positive movement of the strand line in late Pleistocene times in Northwestern North America may be a result of the return of water to the ocean basins from wasting ice caps. The simple effect of ice melting is, however, complicated in the region under discussion by close proximity to the ice masses. Here, too, sea transgression has been followed by a presumably much greater negative movement of the strand, which has continued nearly or quite to the present time. Barrell's[2] discussion of the various problems involved is especially stimulating in this connection.

Three factors enter into the local problem: elevation of sea-level due to return of water which had been congealed on the land; depression of sea-level due to decreasing gravitative attraction of the ice masses; and uplift of the land due to isostatic, or other, readjustment consequent upon removal of ice burden. None of the three can be exactly evaluated from the data now available, and the effect of the third can be estimated only from field evidence. Mathematical calculations will, however, help to crystallize opinion concerning their interaction.

Woodward's classic contribution[3] to the subject does not exactly meet the situation at hand. His assumptions concerning area and

[1] H. P. Little, "Pleistocene and Post-Pleistocene Geology of Waterville, Maine," abstract of paper presented before the Geological Society of America, December, 1916.

[2] J. Barrell, "Factors in Movements of the Strand Line and Their Results in the Pleistocene and Post-Pleistocene," *Am. Jour. Sci.* (4), XL (1915), 1–22.

[3] R. S. Woodward, "On the Form and Position of the Sea-Level," *U.S. Geol. Survey Bull. 48*, 1888.

thickness of the ice cap were made with the expressed purpose[1] of determining the "maximum upheaval of the water" possible as a result of glacial conditions. I have, therefore, with indispensable assistance from my wife, computed the results obtained from his formulas on the basis of quite different assumptions, which are believed to be more in accord with known data concerning the Labradorian ice sheet.

For mathematical purposes it is fair to assume a circular ice cap with a radius of 14°, or about 966 miles, on the earth's surface and a thickness at its center of 5,000 feet. Let its surface configuration correspond to $n = 10$ in Woodward's equation 95.[2] This would give an increasingly rapid slope of the ice surface from center to border as in the following table:

	Slope in Feet per Mile of Ice Surface at Varying Distances, Expressed in Degrees, from Center of Assumed Ice Cap					
Center.....	4°	6°	8°	10°	12°	Border
.00.....	.00	.02	.34	2.53	12.95	51.43

From equation 96 it follows that such an ice cap would lower the sea-level 82.5 feet, if all its ice were formed from moisture withdrawn from the ocean. Following the method of Woodward in § 49,[3] we find that the gravitative attraction of this ice sheet would distort the level of the sea so that the disturbed surface along the border of the ice mass would be 136 feet above the undisturbed surface. The average slope of the disturbed surface within one degree of the ice border would be 0.13 feet per mile. If the ice cap were 10,000 feet in thickness at its center, the distortional effect would be twice as great as that of a 5,000-foot cap of the same diameter and surface contour.

There is every reason for believing that the development of the half-dozen ice sheets which covered parts of North America and Europe in Pleistocene times was practically synchronous. The total effect of all must, therefore, be considered in evaluating

[1] *Ibid.*, p. 18.

[2] *Ibid.*, p. 62.

[3] *Ibid.*, pp. 65–66.

resultant changes in sea-level. Daly[1] has presented the requisite data for estimating the area, ice-covered during the Pleistocene, which is now freed from its glacial burden. If the ice averaged 5,000 feet in thickness over this area, the sea-level would have been lowered about 235 feet by abstraction of water. In comparing this figure with the 136 feet of elevation at the border of the assumed Labradorian ice sheet it should be remembered that a considerable body of Pleistocene ice existed at distances of more than 45° from its border and would have exerted an attraction in the opposite direction.

It seems safe to conclude that at no time or place was the gravitative attraction of a Pleistocene ice cap powerful enough to elevate sea-water at its border sufficiently to overcome the lowering of sea-level due to withdrawal of water from the sea. This means that so far as these two factors are concerned the movement of the strand line was everywhere negative during the time of advancing ice and positive during the waning stages.[2] Near the ice borders the movement was in each case less in amount than in lower latitudes, but its direction was the same. Disregarding secular adjustment within the earth, the retreat of the Labradorian ice front from Covey Hill northward must have resulted in a progressively more extensive submergence of the St. Lawrence-Ontario Valley.

For present purposes it is unnecessary to make any inquiry into the causes of the differential uplift of northern lands which is known to have occurred since retreat of the Labradorian ice sheet began. It is, however, essential to know the time relations between the withdrawal of the ice and the readjustments which so convincingly appear to be of an isostatic nature. Did the land mass respond so quickly that secular movement entirely compensated the rising sea-level and thus maintained a stationary, or even a retreating, strand-line? Or did crustal deformation lag behind unloading of the ice burden sufficiently to permit an upward movement of the sea-level to precede the upward movement of the land?

[1] R. A. Daly, "The Glacial-Control Theory of Coral Reefs," *Proc. Amer. Acad. Arts and Sci.*, L (1915), 172.

[2] Cf. C. Schuchert, "The Problem of Continental Fracturing and Diastrophism in Oceanica," *Amer. Jour. Sci.* (4), XLIII (1916), 92, 93.

The philosophy of diastrophism is not sharply enough defined to permit an a priori answer to this question. On the one hand are many data, such as those obtained by Michelson[1] in his study of tides, which indicate quick response to external strain; on the other hand are just as many, if not more, facts, such as those concerning periodicity of orogenic episodes, which indicate the ability of the earth to delay adjustment for some time after strains begin to accumulate.

Field evidence in the Great Lakes region strongly suggests considerable lag of continental uplift behind ice removal. Postglacial marine fossils in the Hudson's Bay drainage basin occur at elevations at least as great as 450 feet[2] and indicate uplift of that amount since the Labradorian ice sheet shrank to a diameter of less than two or three hundred miles. The highest shore line of the Champlain Sea rises toward the north at an average gradient of more than $2\frac{1}{2}$ feet per mile and is essentially parallel to the Iroquois strand—sufficient proof in itself that the uplift of the St. Lawrence region, in greater part at least, lagged considerably after removal of the ice load.

The facts concerning Quaternary diastrophism in the region covered by the Labradorian ice sheet seem to be in complete agreement with the conclusion reached from field evidence in Napanee Valley, namely, that the late Wisconsin and Recent uplift did not cause the marine strand to retreat until after an appreciable interval of sea-advance had resulted from the melting of the ice.[3]

[1] A. A. Michelson, "Preliminary Results of Measurements of the Rigidity of the Earth," *Jour. Geol.*, XXII (1914), 97–130.

[2] A. P. Coleman, "Lake Ojibway; Last of the Great Glacial Lakes," *Ontario Bur. Mines, Ann. Rep.*, XVIII (1909), 284–93.

[3] In determining the amount of deformation affecting the shore lines of an inclosed body of water, such as Lake Iroquois, during its existence, the distortion of its surface by gravitative attraction should by no means be disregarded. Retreat of the ice front will, in effect, carry the inclined plane of the water surface northward and at the same time cause it to approach more closely a horizontal position. The result will be splitting of beaches north of the lake's outlet, and drowning of the older shore features south of the outlet. This apparent, though not real, warping of the basin was in many cases of sufficient amount to be of quantitative importance. One reason why the Nipissing beach, although tilted, departs but little from a true plane, while the Algonquin and earlier beaches are warped as well as tilted, is that Lake Nipissing was not a marginal glacial lake, as were its predecessors.

SUMMARY

Withdrawal from the Thousand Island region of the Labradorian ice barrier responsible for the existence of Lake Iroquois was followed by accumulation of fluvio-glacial gravels in Napanee Valley. The pro-glacial stream descended to a locality which is now less than 325 feet above sea-level before it debouched into Gilbert Gulf, an arm of the Champlain Sea. At the same time Algonquin River carried the overflow from Lake Algonquin down Trent Valley past Trenton, Ontario, to an outlet which is now beneath the waters of Lake Ontario.

The melting-back of the ice front from Covey Hill toward the Height of Land was contemporaneous with a positive movement of the strand-line which carried marine waters toward the head of the Ontario basin and drowned the Napanee and Trent valleys. The positive movement of the strand-line was followed by a negative movement, which began approximately at the time of complete disappearance of Labradorian ice and has continued nearly or quite to the present time.

Disregarding crustal movement, the waning of Pleistocene ice caps would result in a world-wide transgression of the sea as its volume was increased by the return of water temporarily abstracted to form the ice masses. In high latitudes the amount of movement of sea-level would be much less than in low, because of gravitative attraction of the ice, but everywhere the direction of movement would be the same.

Secular adjustment following removal of ice load was delayed in the Ontario-St. Lawrence region long enough to permit a stage of sea-advance before upward tilting overcame the effect of ice-melting and the stage of sea-retreat was reached.

THE RELATIONSHIPS OF THE FOSSIL BIRD *PALAEOCHENÖIDES MIOCEANUS*

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In a recent number of the *Geological Magazine*[1] Dr. R. W. Shufeldt described and figured the fossilized distal end of the right femur of a bird from South Carolina, proposing for it the name *Palaeochenöides mioceanus*. This Dr. Shufeldt considered as representing a large anserine form. Through the courtesy of Dr. O. P. Hay, I have had opportunity of comparing this type, and after careful study am forced to disagree with Dr. Shufeldt as to the affinities of the species represented. After careful comparison with many specimens I am convinced that the fragment does not come from an anserine bird, but that it represents a large steganopod, related (though not closely) to our modern brown pelicans.

When the specimen was first examined, the popliteal area of the bone was obscured by matrix that covered and obliterated contours and slight depressions. This was carefully removed, and these characters made fully visible (Fig. 1). Though at first glance there are certain resemblances to the swans, these characters are found to be superficial and to lose their value upon careful study. The anseriform species available that show certain resemblances to *Palaeochenöides* are the following: *Olor buccinator*, *O. americanus*, *O. cygnus*, *Branta canadensis*, *Chen caerulescens*, and *Dendrocygna autumnalis*. A considerable number of other species have been examined, but have been found to resemble the above closely or to be so different as not to be pertinent in the present case. In the Steganopodes the following have been utilized: *Phaëthon aethereus*, *Fregata magnificens*, *Sula leucogastra*, *S. bassana*, *S. serrator*, *Pelecanus fuscus*, and *P. onocrotalus*. The cormorants and darters are highly

[1] 1916, pp. 343–47 (Pl. XV).

specialized, so that, though several species of *Phalacrocorax*, *Nannopterum*, and two species of *Anhinga* were examined, they were not directly comparable. In the following table I have drawn up in parallel columns the salient differences in the distal end of the

FIG. 1.—Lower surface of distal portion of femur (type) of *Palaeochenöides mioceanus*.

femur in the species enumerated in the two groups. An asterisk indicates which group *Palaeochenöides* resembles in the characters designated.

Anseres	Steganopodes
1. Intercondylar notch deep, narrow.*	1. Intercondylar notch more shallow, broader.
2. Femur non-pneumatic.	2. Femur pneumatic.*
3. Condyles well elevated on dorsal surface, rising abruptly from shaft.	3. Condyles little elevated on dorsal surface, merging in a long gradual slope into shaft.*
4. Ventral surface of femur behind condyles more rounded, lateral margins strongly rounded.	4. Ventral surface of femur behind condyles flattened, lateral margins angular or very slightly rounded.*
5. Tuberosity above fibular facet of outer condyle extending at an angle across outer third of shaft.	5. Tuberosity above fibular facet of outer condyle lateral, following line of shaft.*

It is seen that in four of these major differences *Palaeochenöides* agrees with the Steganopodes, while in only one does it approach the Anseres. Other differences of less constant value are present between the two groups. In most of the anserine birds the con-

dyles project farther on the ventral surface, and the distal end of the femur is greatly expanded at the condyles, the shaft being slender in comparison. In the Steganopodes (save in the Phalacrocoracidae) the condyles are less produced ventrally and there is a gradual broadening of the shaft until it merges gradually into the condyles. In the Anseriformes, in general, the lateral diameter of the shaft of the femur where the expansion for condylar support ceases is less than one-half the greatest lateral width through the condyles (the measurement of the shaft in this case not being absolutely its smallest diameter, but usually the breadth at a point one-third of the length of the femur from its distal extremity). In the Sulidae, the brown pelicans, and the snake-birds this diameter is more than one-half of the condylar width. Some cormorants have it greater (*P. albiventris*), and some less. In all of these points *Palaeochenöides* resembles the totipalmate birds, and it is referred without question to the Steganopodes. The distal end of the femur representing *Palaeochenöides*, while similar to that of our present-day pelicans, differs in having a posterior pneumatic foramen, the popliteal space divided by a rounded elongate ridge (extending at an angle posteriorly from the pneumatic fossa), the outer condyle broader and stronger, and the intercondylar channel deeper and more narrow, with no depression evident on the dorsal face of the shaft immediately posterior to the origin of the condylar ridges. Should more of the skeleton become known, it may eventually be placed in a separate family. If we may venture to base theory upon this one fragment, *Palaeochenöides* was a pelican-like bird somewhat larger than *Pelecanus erythrorhynchos* or *P. onocrotalus*, as the portion of the femur representing it seems to indicate that the bone in its entirety was somewhat larger and heavier than the femur in these two species. In its appearance this bone seems, too, to show certain resemblances to the Sulidae and remotely to the Anhingidae and the Phalacrocoracidae. Hence, while *Palaeochenöides* will stand as a milepost in the line of descent of the pelicans, it brings down to us suggestions of generalized development indicating ancient relationships of pelicans to gannets and more remotely to the cormorant-anhinga branch of the totipalmates.

A STUDY OF THE FAUNAS OF THE RESIDUAL MISSISSIPPIAN OF PHELPS COUNTY (CENTRAL OZARK REGION), MISSOURI

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In the reports of the early writers on the geology of the Ozark region in Missouri mention is made of scattered patches of bowlders containing fossils of "Chemung age" occurring in counties where no rocks of this age are in place or where they are but sparingly represented.

The investigations of Shumard, Meek, and Broadhead for the Missouri Bureau of Geology and Mines, between 1855 and 1871, published in 1873, mention such bowlders from Maries, Miller, Morgan, Phelps, Wright, and Ozark counties.[1] This list of localities is doubtless incomplete, since much of the region was not examined by these workers. Meek assigned these bowlders to the Lower Carboniferous, but Shumard and Broadhead employ the older term Chemung. Shortly before the publication of the report, the so-called "Chemung Group" of the older Missouri geologists was shown to be Lower Carboniferous, and in a footnote in Shumard's report on Ozark County,[2] he states that the term Chemung as employed in these reports is to be understood to mean Lower Carboniferous.

Broadhead again mentions these deposits in his report for 1873–74, as follows: "Fragmentary outliers of this group [Chouteau] are occasionally found capping the ridges near the Arkansas line."[3]

[1] Missouri Bur. of Geol. and Mines, *Reports of the Geological Survey of the State of Missouri*, 1855–71 (1873). See reports of the various counties named above.

[2] *Ibid.*, p. 190.

[3] G. C. Broadhead in Missouri Bur. of Geol. and Mines, *Reports of the Geological Survey of the State of Missouri*, 1873–74 (1874), p. 27.

In 1898 Broadhead, writing on the Ozark uplift and the growth of the Missouri Paleozoic,[1] states that "beds of Chouteau limestone" have been found in Wright and Maries counties, and that the Burlington limestone has been recognized in Morgan, Benton, and Hickory counties, from which he concludes that at least the western half of the Ozark uplift was submerged during the Lower Carboniferous period.

The work of the present Missouri Bureau of Geology and Mines has given some additional information concerning the distribution of these deposits. Marbut,[2] Ball and Smith,[3] Van Horn and Buckley,[4] and Lee,[5] working in different areas in the northwestern part of the Ozark region, have mentioned these deposits, but up to the present time no careful study has been made either of the distribution of this residual material or of its faunal content. In the literature it is commonly referred to as Chouteau or Burlington. In some localities these deposits are termed "residual Boone Cherts."

The purpose of the present paper is to present the results of a careful study of the faunas contained in a number of these bowlders. The bowlders which have furnished the material for this investigation were all collected within an area of about forty square miles situated in the extreme northeastern part of the Rolla quadrangle and the adjacent portion of Phelps County.

This area is a small plateau the summit of which is capped by resistant formations. The physiography and general geology of the region have been well described by Lee[6] and need not be rediscussed here. The entire plateau is underlain by the Jefferson City dolomite of Canadian age, and lying unconformably upon

[1] G. C. Broadhead, "The Ozark Uplift and the Growth of the Missouri Paleozoic," Missouri Bur. of Geol. and Mines, Vol. XII (1898), *Areal Geology*, p. 398.

[2] C. F. Marbut, "Geology of Morgan County," Missouri Bur. of Geol. and Mines, Vol. VII (1907), 2d ser., pp. 49–51.

[3] S. H. Ball and A. F. Smith, "Geology of Miller County," Missouri Bur. Geol. and Mines, Vol. I (1903), 2d ser., pp. 82–89.

[4] F. H. Van Horn and E. R. Buckley, "Geology of Moniteau County," Missouri Bur. of Geol. and Mines, Vol. III (1905), 2d ser., pp. 44–58.

[5] Wallace Lee, "Geology of the Rolla Quadrangle," Missouri Bur. of Geol. and Mines, Vol. XII (1913), 2d ser., pp. 41–43.

[6] *Ibid.*, pp. 52–58, 13–40.

this are patches of non-fossiliferous sandstone and fire clays, which on lithologic grounds are classed as basal Pennsylvanian. The area covered by these Pennsylvanian deposits is not definitely known, but recent work has shown that its extent is much greater than has heretofore been supposed. It probably caps the divide almost continuously from Rolla to Cuba and for a considerable distance northeast of Cuba. Around the edges of this plateau where the Pennsylvanian is wanting, but where the Jefferson City formation is still in place, there are found small areas which are covered with Mississippian bowlders. They rarely cover more than a few acres and may or may not be associated with similar deposits of Pennsylvanian age. They have an average vertical distribution of about thirty-five feet and a maximum of eighty feet. The total relief of the Rolla area is about five hundred feet, but the bowlder patches are confined to the upper two hundred feet. They occur at lower levels in the northern part of the area, owing to the slight dip of the underlying formations.

The bowlders almost invariably occur on the hillsides or in the heads of small ravines. A few patches have been found upon the hilltops, but in every case the crest of that particular hill was below the general summit-level. In the places where one of the bowlder areas is associated with a small outlier of Pennsylvanian it may completely encircle it, but in most cases forms a fringe on one side only, which would seem to indicate that these bowlder areas were localized in some manner before the deposition of the Pennsylvanian.

The exact nature of the Mississippian-Pennsylvanian unconformity is still doubtful. Outliers of Mississippian rocks occur in some parts of the Ozark region, but up to the present none have been found in this area. Small isolated patches of stratified Mississippian may be buried beneath the Pennsylvanian, but at the present time no such occurrences have been reported. At one locality fragments of the Mississippian have been found in the basal conglomerate of the Pennsylvanian,[1] but such association is not common. It may be that these patches of bowlders are the remnants of small outliers which have been reduced to this stage since the

[1] Wallace Lee, *op. cit.*, p. 44.

erosion of the Pennsylvanian, but there is also the possibility that these deposits were in the bowlder form before the invasion of the Pennsylvanian seas. In either case the character of the bowlders seems to indicate that they have not been moved far from their place of origin, if they have been moved at all.

Lithologically the bowlders fall into a number of well-marked groups. The more abundant ones are of course, dense, quartzitic sandstone, which in its original state was probably a calcareous sandstone. In their present condition the calcium carbonate content has been completely removed by leaching, and thin sections show them to be made up entirely of clear quartz grains exhibiting little evidence of secondary growth. The interior of these bowlders is semi-translucent, bluish white in color, and the rock is quite hard and dense, but the more weathered, external portions are extremely porous and deeply stained with iron oxide. They are abundantly fossiliferous, but the fossils are scattered irregularly through the rock with no arrangement that would suggest bedding. Associated with the quartzitic bowlders are masses of soft, friable, fine-grained white sandstone, which are somewhat leached and in which the more weathered phases are deeply stained with iron oxide. Otherwise the rock is but little altered. The fossils of these sandstone masses are arranged in parallel bands, which probably correspond to the bedding planes of the formation.

Bowlders of chert are also abundant. Some are practically unweathered, others are so completely leached that they powder under the hammer. For the most part they are white or pale bluish white in color, and, like the sandstone bowlders, they are stained with iron oxide in proportion to the amount of weathering which they have undergone. At one locality a single chert bowlder has been found which is of a pale pink color, the color appearing to be original.

Lee[1] has mentioned that bowlders of siliceous oölite of Mississippian age occur at one locality associated with bowlders of the quartzitic type. A careful examination of such oölite bowlders from this and other localities where they are associated with residual

[1] *Ibid.*, p. 42.

Mississippian deposits has failed to disclose any determinable Mississippian fossils. Some of the oölite is conglomeratic, containing small angular chert pebbles, and much of it contains small cavities, some rounded, others angular, which simulate the impression of poorly preserved fossils. Lee has suggested that this oölite is the possible equivalent of the Short Creek oölite of southwestern Missouri. The writer has not seen Lee's collections from the fossiliferous oölite, and his own observations have not confirmed Lee's. Bowlders of siliceous oölite are abundant in the residual material over a large part of this area. There are beds of it in the Jefferson City formation, and some oölite bowlders have been found which contain Canadian fossils. On the other hand, many of the oölite bowlders are weathered and stained with iron oxide in much the same manner as are the Mississippian bowlders, while others do not seem to have been weathered in this manner.

The association of the different types of bowlders seems to follow no general rule. In some localities they consist exclusively of sandstones, while in others chert predominates, but in nearly every case examples of all the easily recognized lithologic types are to be found together.

The fossils are in most cases preserved as molds of the exterior and as casts of the interior. In rare instances the shell itself, together with the internal structures, has been completely silicified. In many examples the molds and internal casts preserve the markings of the original with great fidelity, and excellent squeezes may be obtained from them. Some difficulty has been experienced in correlating the mold with the internal cast, for, strangely enough, when one surface is well preserved, the other often is not.

The material used in the preparation of this paper has come from three sources: (1) a collection belonging to the Department of Geology of the Missouri School of Mines and Metallurgy, lent by Professor Cox and Professor Dake; (2) some collections belonging to the Missouri Bureau of Geology and Mines, lent by Mr. Buehler; and (3) a number of collections made by the writer and his friends. These were made while the writer was connected with the Missouri School of Mines and are the property of that institution.

At the outset it was realized that in order to get decisive results the faunas of each individual bowlder must be kept together so that the natural association of species might be determined. This has been done, and a record of the localities from which the individual bowlders have come has also been kept. The original collection of the School of Mines was made without regard to the first factor and with but slight regard to the second, so that, while it contains many fine specimens which have been of great value in making comparisons, it has been useless for exact stratigraphic purposes. The collections of the Missouri Survey and those made by the writer were made with both of the above-mentioned points in view, and all of the conclusions drawn from this study are based upon the faunas which they have yielded. Numbers have been assigned to the several localities from which collections have been made, and these, together with the location, are given in the accompanying list.

REGISTER OF LOCALITIES, PHELPS COUNTY, MISSOURI

1. T. 38 N., R. 8 W., N.E. ¼, S.E. ¼, Sec. 36.
2. T. 38 N., R. 8 W., N.E. ¼, N.E. ¼, Sec. 36.
3. T. 38 N., R. 8 W., S.W. ¼, S.E. ¼, Sec. 25.
4. T. 37 N., R. 8 W., N.W. ¼, S.W. ¼, Sec. 26.
5. T. 37 N., R. 8 W., Center line S. ½, Sec. 25.
6. T. 38 N., R. 8 W., S.E. ¼, S.W. ¼, Sec. 27.
7. T. 38 N., R. 8 W., W. ½, S.W. ¼, Sec. 27.
8. T. 37 N., R. 8 W., S.W. ¼, S.W. ¼, Sec. 24 and adjoining corners in Secs. 24 and 25.
9. T. 38 N., R. 8 W., S.W. ¼, S.E. ¼, Sec. 35.
10. T. 38 N., R. 8 W., N.W. corner N.W. ¼, N.E. ¼, Sec. 35.
11. T. 38 N., R. 8 W., N.W. ¼, N.W. ¼, Sec. 36.
12. T. 38 N., R. 8 W., Center S.E. ¼, Sec. 26.

MARIES COUNTY, MISSOURI

1. T. 40 N., R. 8 W., Sec. 7.

Lee's map shows the location of most of the localities listed above.

The oldest Mississippian fauna which this area has yielded is contained in the bowlder of pink chert, mentioned on page 561. The bowlder is case-hardened and stained with iron oxide to the

depth of about one-eighth of an inch. It is somewhat leached, but otherwise is scarcely weathered. The following fauna was obtained:

FAUNA OF BOWLDER 28, LOCALITY 7

Coelenterata
- Zaphrentidae
  - Gen.? sp.?
- Cyathaxonidae
  - *Cyathaxonia* sp.

Echinodermata
- *Platycrinus* sp. (stem fragments)
- Unidentified stem and other fragments

Molluscoidea
- *Fenestella burlingtonensis* Ulr.?
- *Rhombopora* sp.
- **Productus sampsoni* Weller?
- *Rhipidomella diminutiva* Rowley
- *Camarotoechia tuta* (Miller)
- **Dielasma fernglenensis* Weller
- Terebratuloid shell gen.? sp.? (3 forms)
- **Cyrtina burlingtonensis* Rowley
- Spirifer sp. (small form, probably young shell)
- **Spiriferina subtexta* White
- **Brachythyris fernglenensis* Weller?
- *Ambocoelia levicula* Rowley
- *Ambocoelia* sp.
- *Reticularia cooperensis* (Swallow)
- **Ptychospira sexplicata* (W. &. W.)
- **Athyris lamellosa* (Leveille)
- **Cliothyridina glenparkensis* Weller?

A comparison of this fauna with the Fern Glen fauna described by Weller[1] shows that the two have very close relationships. While the fauna of this bowlder is not as large as that of the Fern Glen, the majority of its determined forms are identical with, or closely related to, Fern Glen species. In the faunal list given above the species occurring in the Fern Glen fauna have been designated by an asterisk. Of the ten certainly identified brachiopods, six are recorded in the Fern Glen fauna, and three others, doubtfully identified, are also represented in the Fern Glen. The

[1] Stuart Weller, "Kinderhook Faunal Studies, V, The Fauna of the Fern Glen Formation," *Bul. Geol. Soc. Amer.*, XX (1909), 265–332.

genus *Cyathaxonia* is abundantly represented in the Fern Glen fauna, and *Platycrinus* and *Rhipidomella* also occur. *Camarotoechia tuta* and *Ambocoelia levicula* are both found in the Lower Burlington limestone, while *Reticularia cooperensis* appears to be a survival from the late Kinderhook. The relationships of this fauna are so definite that there is no hesitation in calling it the equivalent of the Fern Glen fauna.

A somewhat younger fauna has been obtained from a number of quartzitic bowlders, and the faunas of the four best bowlders containing this fauna have been combined to form the list given in Table I.

A comparison of the four faunas listed (p. 566) shows that they are closely related. Only one species is common to all four faunas, but three species are common to faunas Nos. 3 and 5, seven to faunas Nos. 31 and 5, five to faunas Nos. 17 and 5, etc. The bowlders in which these faunas were contained were all small, and this would partially account for some of the diversity.

The affinities of these faunas are with the Burlington rather than with the Kinderhook. Many of the species are common to the Upper Kinderhook and the Lower Burlington, and recent work has suggested that some beds which have commonly been referred to the upper part of the Kinderhook are more nearly related to the base of the Burlington. This fauna is not the equivalent of the Fern Glen fauna just described; neither is it the exact equivalent of the fauna of the Burlington White Chert from Louisiana, Missouri, but appears to be intermediate between the two. Very few faunas have been described from this horizon, and, until more definite work is done on this portion of the Mississippian, a more exact correlation cannot be made.

The faunas of the eight bowlders listed in Table II have much in common, and undoubtedly are from a common horizon.

Of the 72 forms listed in Table II, 50 are found in the Burlington of various localities, and at least 11 more occur in the Fern Glen and in beds of equivalent age. A few forms hitherto reported only from the Upper Kinderhook and Chouteau—*Chonophyllum sedaliense*, *Reticularia cooperensis*, *Productus blairi*, and *Hustedia circularis*—are also recorded. Some of these are definitely identified;

the presence of others is doubtful, but their presence does not affect the correlation of the faunas. Some of the bryozoans listed

TABLE I

Locality No. / Bowlder No.	7 / 31	10 / 3	10 / 5	10 / 17
Coelenterata				
Zaphrentis calceola W. & W.	x	x	x	x
Echinodermata				
Cryptoblastus melo O. & S.			x	
Platycrinus ? sp.				x
Undet. crinoid base			x	
Molluscoidea				
Fenestella cf. *F. exigua* Ulr.				x
Polypora sp.			x	
Schellwienella sp.	x		x	
Chonetes multicosta Winchell			x	x
Chonetes sp. undesc.		x		
Productus sampsoni Weller			x	
Productus ferneglenensis Weller	x		?	
Productus burlingtonensis Hall			?	
Productus sp.			x	
Rhipidomella diminutiva Rowley	x	x		
Schizophoria chouteauensis Weller	x			
Schizophoria swallovi (Hall)	x			
Schizophoria subelliptica (W. & W.)		x		
Schizophoria sp.			x	
Camaroloechia sp.			x	x
Rhynchopora sp.			x	
Cranaena globosa Weller				x
Dielasma osceolensis Weller?				x
Spiriferina sp.		x		
Spirifer osagensis Swallow	x	x	x	
Spirifer vernonensis Swallow	x		x	
Spirifer latior Swallow	x			
Spirifer louisianensis Rowley	x		x	x
Spirifer legrandensis Weller	cf.			
Spirifer platynotus Weller	?	x		
Spirifer biplicoides Weller			x	x
Spirifer sp. nov.			x	
Spirifer sp.			x	
Spirifer sp.			x	
Brachythyris ? sp.	x			
Syringothyris sp.	x			
Ambocoelia levicula Rowley		x	x	
Nucleospira obesa Rowley	x			
Cliothyridina tenuilineata (Rowley)				x
Mollusca				
Conocardium sp. nov.	x		x	
Euomphalus latus Hall	x	x		
Platyceras obliquus (Keyes)				x
Orthonychia sp.	x			
Igoceras? sp.			x	
Arthropoda				
Phillipsia meramecensis Shumard				x

TABLE II

Locality No. / Bowlder No.	1 MGS 2	4 101	5 100	10 4	10 2	10 27	1 MGS 1	12 MGS 3
Coelenterata								
Zaphrentis calceola W. & W.	x	x	.....	x	.....	.....	x	x
Zaphrentis sp. undet.	.....	.....	.....	.....	.....	.....	.....	x
Zaphrentis sp. undet.	.....	.....	.....	.....	.....	.....	.....	x
Zaphrentis sp. undet.	.....	.....	.....	.....	.....	.....	x	.....
Triplophyllum centralis (E. & H.)	.....	x	.....	.....	.....	.....	.....	.....
Triplophyllum sp.	.....	x	.....	.....	.....	.....	.....	.....
Amplexus fragilis White & St. John	.....	x	.....	.....	.....	.....	.....	.....
Chonophyllum sedaliense White	.....	x	.....	.....	.....	.....	.....	.....
Echinodermata								
Cryptoblastus melo O. & S.	.....	.....	.....	x	.....	.....	x	x
Batocrinus? tuberculatus? W. & S.	.....	.....	.....	.....	.....	x	.....	.....
Aorocrinus?? sp.	.....	.....	.....	.....	.....	.....	x	
Actinocrinidae gen.? sp.?	.....	.....	.....	.....	.....	.....	x	
Platycrinus sculptus Hall	.....	cf.	.....	.....	.....	.....	.....	.....
Platycrinus sp. (several)	3	x	x	.....	x	.....	x	2
Crinoid fragments, plates, stems	x	x	x	x	x	x	x	x
Molluscoidea								
Fenestella filistriata Ulr.	?	.....	.....	.....	.....	?	.....	.....
Fenestella multispinosa Ulr.	?	.....	?	.....	.....	.....	.....	.....
Fenestella compressa var. *elongata* Cumings	x	x	.....	.....	.....	.....	.....	x
Fenestella burlingtonensis Ulr.	.....	.....	.....	.....	.....	?	.....	.....
Fenestella? sp.	.....	.....	.....	.....	.....	x	.....	.....
Fenestella? sp.	.....	.....	.....	.....	.....	.....	.....	x
Fenestella? sp.	x	.....	.....	.....	.....	.....	.....	.....
Hemitrypa? sp.	x	.....	.....	.....	.....	.....	.....	.....
Fenestelloid gen., sp.	x	.....	.....	.....	.....	.....	.....	.....
Rhombopora sp.	x	.....	.....	.....	.....	.....	.....	.....
Glyptopora sp.	.....	.....	.....	.....	.....	.....	.....	x
Leptaena analoga (Phillips)	.....	x	.....	.....	.....	.....	.....	.....
Schellwienella alternata Weller	x	.....	.....	.....	.....	.....	.....	.....
Schellwienella inflata W. & W.	cf.	x	.....	.....	.....	.....	.....	.....
Schellwienella burlingtonensis Weller	.....	x	.....	x	.....	.....	.....	x
Schellwienella or *Streptorhynchus* sp.	.....	x	.....	x	.....	.....	.....	x
Streptorhynchus sp.	.....	x	.....	.....	.....	.....	.....	.....
Chonetes glenparkensis Weller	x	.....	.....	.....	.....	.....	.....	.....
Chonetes multicosta Winchell	.....	.....	.....	x	.....	.....	.....	x
Chonetes illinoisensis Worthen	.....	.....	.....	.....	.....	.....	x	x
Chonetes logani N. & P.	.....	.....	.....	.....	.....	.....	.....	x
Chonetes sp. nov.	.....	x	.....	.....	.....	.....	.....	.....
Chonetes sp.	x	.....	.....	.....	.....	.....	.....	.....
Chonetes sp.	.....	.....	.....	.....	.....	x	.....	.....
Productella concentrica (Hall)	.....	x	.....	.....	.....	.....	x	.....
Productella millespinosa Girty	.....	.....	.....	.....	.....	x	.....	.....
Productus ovatus Hall	x	.....	.....	.....	.....	?	.....	x

TABLE II—*Continued*

Locality No. / Bowlder No.	1 MGS 2	4 101	5 100	10 4	10 2	10 27	1 MGS 1	12 MGS 3
Molluscoidea—*Continued*								
Productus sampsoni Weller	x						x	x
Productus sedaliensis Weller	cf.							cf.
Productus blairi Miller	cf.							
Productus burlingtonensis Hall		x						x
Productus ferngleneusis Weller		?					?	
Productus sp.								x
Rhipidomella burlingtonensis (Hall)	x						x	x & cf.
Rhipidomella diminutiva Rowley	x	x						x & cf.
Rhipidomella thiemei (White)							x	
Rhipidomella sp.		x						
Schizophoria chouteauensis Weller	cf.							x
Schizophoria swallovi (Hall)		x						
Schizophoria poststriatula Weller								x
Camarophoria bisinuata (Rowley)						x		
Camarotoechia tuta (Miller)		x						x
Camarotoechia sp.							x	
Rhynchopora persinuata (Winchell)								x
Centronelloidea rowleyi (Worthen)		x					x	
Cranaena globosa Weller							x	
Dielasma chouteauensis Weller	x							
Dielasma osceolensis Weller		x						
Dielasma sp.	x							
Spiriferina subtexta White	x	x				x	x	
Spiriferina solidirostris White								x
Spiriferina sp.					x	x		
Delthyris novamexicana (Miller)						?		
Spirifer louisianensis Rowley	x	x	x				x	x
Spirifer vernonensis Swallow	?	x					?	x
Spirifer insculptus Rowley	x							
Spirifer platynotus Weller	?	?						?
Spirifer biplicoides Weller		x						x
Spirifer gregeri Weller		x				?		
Spirifer osagensis Swallow		x					x	x
Spirifer forbesi N. & P.				x			x	x
Spirifer carinatus Rowley							?	
Spirifer rowleyi Weller								x
Spirifer sp.		x						
Spirifer sp.		x						
Spirifer sp.								3
Spirifer sp. (young shell)							x	x
Spirifer? sp.						x		
Brachythyris chouteauensis Weller	x						x	x
Syringothyris sp.								x

TABLE II—*Concluded*

Locality No. Bowlder No.	1 MGS 2	4 101	5 100	10 4	10 2	10 27	1 MGS 1	12 MGS 3
Mulloscoidea—*Continued*								
Pseudosyrinx missouriensis Weller						x		
Ambocoelia levicula Rowley	x		x		x	?		
Reticularia cooperensis (Swallow)	x					x	x	x
Ptychospira sexplicata (W. & W.)	?							
Eumetria? sp	x							
Hustedia circularis (Miller)						x		
Nucleospira obesa Rowley	x							
Rowleyella fabulites (Rowley)						x		
Athyris lamellosa (Leveille)						x		
Cliothyridina tenuilineata (Rowley)	x	x					x	x
Composita sp		x						
Mollusca								
Conocardium sp. nov		x	x					
Cypricardinia sp							x	x
Laevidentalium sp	x							
Lepetopsis sp	x							
Pleurotomaria sedaliensis Miller			x					
Platyschisma? depressa		cf.						
Euomphalus latus Hall		x	x				x	x
Strophostylus bivolve W. & W.	x				x			x
Orthonychia sp								x
Orthonychia sp	x		x			x		x
Platyceras nasutus Miller		?						
Platyceras paralius W. & W.							x	
Platyceras obliquus Keyes								x
Platyceras sp						x		
Arthropoda								
Phillipsia tuberculata M. & W.	x	x						
Griffithides sedaliensis Vogdes	x	x	x		x			

above have been described from higher formations only, but as yet the exact range of the Mississippian fenestelloid species is imperfectly known, and such species might well be represented in the earlier faunas. The presence of such fossils as *Centronelloidea rowleyi*, *Rowleyella fabulites*, *Nucleospira obesa*, and *Ambocoelia levicula*, which are characteristic of the white chert division of the Lower Burlington at Louisiana, Missouri, together with the great assemblage of Lower Burlington forms, would seem to indicate that this was the proper correlation for these faunas.

Bowlder No. 16, Locality 10, has yielded but two forms—*Syringothyris platypleurus* Weller, and *Conocardium* sp. nov. The former is a typical Lower Burlington form, and the latter is identical with forms described from the bowlders referred to the Burlington white chert. While it is not possible to place such a small fauna definitely, such evidence as there is seems to indicate that it should be correlated with the bowlders which have just been described. These faunas, with the exception of the one from bowlder No. 27, were obtained from bowlders of sandstone or quartzite. Bowlder No. 27 was composed of white chert. As a general rule, however, it may be stated that the Burlington faunas are to be looked for in the quartzite bowlders, and the younger and older faunas in the cherts.

A number of other bowlders have yielded faunas which are apparently Lower Burlington in age, but which do not contain a fauna which may be classed as being truly representative. These faunas are listed below:

LOCALITY 10—BOWLDER NO. 1

Platycrinus sp.
Cliothyridina tenuilineata (Rowley)

LOCALITY 10—BOWLDER NO. 6

Productus sp.
Rhipidomella diminutiva Rowley
Terebratuloid shell gen.? sp.?
Spirifer biplicoides Weller
Spirifer gregeri Weller?
Spirifer sp.

LOCALITY 12—BOWLDER NO. 19

Fenestella compressa var. *elongata* Cumings?
Brachythyris sp.
Phillipsia tuberculata M. & W.

LOCALITY 7—BOWLDER NO. 21

Spirifer platynotus Weller
Spirifer rowleyi Weller?
Spirifer sp. nov.
Unidentified crinoid

The largest fauna which has thus far been obtained has come from a large chert bowlder which was found by Professor Dake.

This bowlder is so completely weathered that the original texture is entirely gone, and in its place is a porous siliceous mass which powders and crumbles and breaks irregularly. The original bedding of the formation to which this bowlder belonged is well preserved in the specimen and is indicated by a slight lithologic change and a more marked faunal change. Crinoid fragments and pieces of bryozoans are to be found in all parts of the mass, but the former are much more abundant on one side and the latter on the other, and the dividing line is plainly marked. At first an attempt was made to keep the faunas of the two sides separate, but it was soon found that specimens of practically all the species represented were found on both sides of the bowlder. The two faunas are therefore treated as one.

FAUNA OF BOWLDER 102—LOCALITY 1

Coelenterata

Amplexus fragilis White & St. John
Monolipora beecheri Grabau
Gen.? sp.?

Echinodermata

Codaster sp. nov.
Platycrinus hemisphericus M. & W.
Platycrinus pratteni Worthen?
Platycrinus sp., at least five species, probably more
Dichocrinus scitulus Hall?
Dichocrinus sp.
Fragments

Molluscoidea

Fenestella cestriensis Ulr.?
Fenestella cingulata Ulr.
Fenestella compressa Ulr.
Fenestella compressa var. *elongata* Cumings
Fenestella compressa var. *nododorsalis* Ulr.
Fenestella exigua Ulr.?
**Fenestella filistriata* Ulr.
**Fenestella filistriata* Ulr.?
Fenestella funicula Ulr.
Fenestella limitaris Ulr.
Fenestella multispinosa Ulr.
Fenestella multispinosa Ulr.?
Fenestella regalis Ulr.
Fenestella rudis Ulr.

Fenestella tenuissima Cumings
Fenestella triserialis Ulr.
Fenestella triserialis Ulr.?
Cystodictya lineata Ulr.
**Polypora burlingtonensis* Ulr.
Polypora gracilis Prout
Polypora hallana Prout
Polypora maccoyana Ulr.
Polypora radialis Ulr.
Pinnatopora conferta Ulr.
Hemitrypa perstriata Ulr.?
Rhombopora dichotoma Ulr.?
Rhombopora incrassata. Ulr.?
**Schellwienella burlingtonensis* Weller
**Productus parvulus* Winchell
†*Productus ovatus* Hall
Productus mesalis Hall?
Pustula biseriatus (Hall)
**Rhipidomella diminutiva* Rowley
**Schizophoria subelliptica* (W. & W.)
Tetracamera missouriensis Weller
Rhynchopora beecheri Greger
**Dielasma burlingtonensis* (White)
**Cyrtina burlingtonensis* Rowley
Cyrtina neogenes Hall and Clarke
**Spirifernia solidirostris* White
Spiriferina norwoodana (Hall)
Delthyris similis Weller
Spirifer rostellatus Hall
Spirifer logani Hall
Spirifer tenuimarginatus Hall?
Spirifer tenuicostatus Hall
†*Brachythyris suborbicularis* Hall
Pseudosyrinx keokuk Weller
Reticularia pseudolineata (Hall)
Eumetria verneuiliana Hall
**Nucleospira obesa* Rowley
**Cliothyridina incrassata* (Hall)
Cliothridina parvirostris (M. & W.)

Mollusca
Cypricardinia sp.
Orthonychia pabulocrinus (Owen)
Platyceras obliquus (Keyes)
Platyceras equilateralis Hall
Undetermined forms

Arthropoda
**Phillipsia tuberculata* M. & W.
Griffithides sedaliensis Vogdes

A careful comparison of this fauna with the extensive collection in the Walker Museum, from the Keokuk and Warsaw formations from a number of localities in the Mississippi Valley, has indicated the approximate age of the fauna, but does not allow it to be placed exactly. Its affinities are with the Upper Keokuk and Lower Warsaw. What little evidence there is seems to favor the placing of this bowlder in the Lower Warsaw.

Spiriferina norwoodana, *Pustula biseriatus*, *Delthyris similis*, *Fenestella exigua*, *F. funicula*, *F. compressa* var. *nododorsalis*, *Polypora gracilis*, and *Pinnatopora conferta* occur in the Lower Warsaw at a number of localities. *Eumetria verneuiliana*, *Pseudosyrinx keokuk*, and *Monolipora beecheri*, while found in both formations, appear to be more abundant in the Lower Warsaw. On the other hand, *Fenestella rudis*, *F. regalis*, *Polypora hallana*, and *P. maccoyana* have heretofore been identified from the Keokuk only. *Spirifer rostellatus* is well known in the Keokuk, but its presence in the Warsaw has been regarded as doubtful.

An interesting recurrent Burlington association appears in this bowlder, the species of which are indicated in the faunal list by an asterisk. A few other species which are common to many Mississippian formations are indicated by the dagger. This recurrent element corresponds almost exactly to the faunas assigned to the Burlington white chert. It is known at the present time that such a recurrent group of species does occur either in the top of the Keokuk formation or in the base of the Warsaw, in southeastern Missouri, and this bowlder was undoubtedly from this horizon originally.

Closely related to the fauna just described are the three faunas listed below:

BOWLDER 13—LOCALITY 10

Archimedes owenanus Hall

MISSOURI BUREAU OF GEOLOGY AND MINES, COLLECTION NO. 4, LOCALITY 12

Archimedes grandis Ulrich
Orthotetes keokuk (Hall)
Productus ovatus Hall

BOWLDER 34—LOCALITY 6

Fenestella rudis Ulrich?
Archimedes grandis Ulrich
Productus ovatus Hall
Productus setigerus Hall
Rhynchopora beecheri Greger
Pseudosyrinx keokuk Weller
Camarophoria? sp.

The exact correlation of these faunas is a difficult matter, since nearly all of the species represented are common to both the Keokuk and the Lower Warsaw. *Archimedes owenanus* is a common Keokuk form, but it also appears in the Lower Warsaw. *A. grandis* is less common, but its stratigraphic range is believed to be about the same as that of *A. owenanus*. *A. wortheni*, which is so characteristic of the Warsaw faunas, has not been found. These faunas are probably best classed as Keokuk. No trace of the recurrent fauna mentioned on page 573, has been found in any of them.

MISSOURI BUREAU OF GEOLOGY AND MINES, COLLECTION NO. 5

Fenestella serratula Ulrich
Fenestella serratula var.
Fenestella serratula Ulrich?
Fenestella exigua Ulrich
Fenestella cf. *exigua* Ulrich
Fenestella exigua Ulrich?
Fenestella sp. (3)
Polypora varsoviensis Prout
Polypora striata Cumings
Polypora spininodata Ulrich
Cystodictya lineata Ulrich
Hemitrypa sp.
Schizophoria sp.
Cypricardinia sp.

This is apparently the youngest fauna which has been found thus far. It is characterized by *Polypora varsoviensis*, the large forms of which are found in great abundance in almost every fragment. This species is common in the Warsaw and younger beds. The specimens referred to *Cypricardina* sp. do not appear to belong to the same species as the ones found in bowlder No. 102,

but are closely related. This fauna is probably Warsaw, but, in the absence of detailed faunal studies of the Warsaw, a more exact correlation cannot be made.

Briefly summarized, the results of this study show that the faunas obtained from these residual bowlders are much more diverse than has previously been supposed. They indicate a partial submergence, in early Mississippian time, of a considerable portion of the northern end of the Ozark uplift. From the study of so small an area, not much is to be inferred as to the movements and distribution of the Mississippian seas during the time when the formations represented in these bowlders were deposited.

Typical Chouteau faunas and pre-Chouteau faunas are conspicuously absent, though farther north the Chouteau formation is represented by small outliers and scattered patches of bowlders. From this it would seem as if the sea did not cover this part of the uplift during Kinderhook time, but that a gradual submergence during the late Kinderhook allowed the Burlington seas to invade this area. This supposition is further strengthened by the sandy character of many of the bowlders, which suggests that the ancient shore line was not far distant. An alternative view is that the Kinderhook formations, or part of them, were present, and, not being as resistant as the younger formations, have entirely disappeared. However, if this is the case, why should the Chouteau formations occur as bowlder deposits in the counties between this area and the Missouri River? On the whole, the evidence seems to favor the first hypothesis.

Not much evidence of the Upper Burlington with its typical crinoid fauna has yet been found, but some specimens in the original School of Mines collection suggest that it was represented. In most places where it is exposed at present it contains much less chert than does the Lower Burlington, and this fact may account for its failure to be more commonly preserved. The Keokuk and the Lower Warsaw are probably both represented, but so great is the similarity between their faunas that the few collections which have been obtained do not suffice to make the distinctions clear. Up to the present time, no evidence has been obtained of any faunas younger than the Lower Warsaw.

EVIDENCE BEARING ON A POSSIBLE NORTHEASTWARD EXTENSION OF MISSISSIPPIAN SEAS IN ILLINOIS

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Introduction.—For some time it has been known that fossils of Mississippian age can be collected within the city limits of Chicago. These Mississippian fossils, which occur in bowlders in the glacial drift, were brought to notice by Mr. William Johnston, who reported them to Professor Weller in 1915. The collections which form the basis of the present report are in part those first secured by Mr. Johnston; others have been collected by Professor Weller, and still others by the writer.

Location of the bowlders.—The drift bowlders which have afforded the fossils occur in the southeastern portion of the clay-pit of the Carey Brick Company, located near the northeastern corner of Grand Avenue and New England Avenue, in the northwestern portion of the city, between Hanson Park and Montclare, being closer to the latter place. The clay-pit is excavated in a terminal moraine, which belongs either to the lake border or to the Valparaiso morainic system, but probably to the former.[1] The morainic

[1] *Areal Geology Sheet,* Chicago Folio.

material contains a considerable number of glacial bowlders of various types and sizes. Some of them are of igneous origin, others carry fossils of Niagaran age. Those containing the Mississippian fauna were observed only in the southeastern part of the pit. The bowlders have been piled into many small heaps by the workmen, several of which are made up almost exclusively of those of Mississippian age. The collections which have been made were largely secured from these piles, but similar bowlders may be found scattered over the southeastern part of the floor of the pit.

Lithologic character of the bowlders.—In their lithologic character these Mississippian bowlders are dolomitic limestones, which closely resemble the Niagaran dolomite of the Chicago region in general appearance; when fresh they are bluish gray in color and very hard, but on weathering they take on an earthy, yellowish-brown color and become very soft.

Physical condition of the bowlders.—The great majority of the bowlders have well-weathered surfaces, and in many examples the outer surface to the depth of an inch or more is decomposed to a soft, yellowish, more or less porous rock as a result of weathering. Some large pieces are completely weathered to the center. This weathered condition of the Mississippian bowlders is, in general, in marked contrast to that of the bowlders of other ages found in the pit. Many of the Mississippian bowlders are rather angular, and none have well-worn faces; they vary in size from small fragments up to irregular blocks containing two or more cubic feet; in general, they lack the characteristic appearance of typical glacial bowlders. If their location were not known, they might easily be mistaken for residual fragments of weathering.

So far as now known, these bowlders are confined to the southeastern section of the Carey clay-pit. A few small masses with the same lithological character were found on the surface of the moraine near the pit, but as none of these fragments have afforded determinable fossils they cannot be identified with certainty.

Criteria by which the bowlders may be recognized.—The Mississippian drift bowlders commonly may be recognized by their dirty, yellowish, weathered surfaces and by their two most marked paleontological characteristics, namely, (*a*) an abundance of

crinoidal remains, mostly stems, and (*b*) the presence of numerous specimens of *Spirifer* with plicated fold and sinus.

The fauna of the bowlders.—These bowlders are abundantly fossiliferous, but the fossils are largely fragmentary and are commonly poorly preserved. Unfortunately they are nearly all in the form of molds, a condition of preservation which has added to the difficulties of their identification. None of the fossils are silicified, but a few of the cavities left by the solution of the shells are sprinkled with crystals of pyrite and dolomite. The extremely weathered portion of the rock is generally too soft to yield determinable fossils, and the unweathered portions yield comparatively few. The great majority of the better specimens have been collected from the partially weathered portions.

The most abundant fossils are the crinoids, although most of the specimens are mere fragments of stems, few of which can be identified even generically, and they are of little scientific value except to show that the rock has been a conspicuously crinoidal limestone. Next to the crinoids the brachiopods are the most common fossils, and owing to their abundance and better state of preservation they form the most satisfactory element of the whole fauna. Besides the crinoids and the brachiopods the fauna contains corals, blastoids, bryozoans, pelecypods, and gastropods, none of which are represented by numerous species or specimens.

The composition of the fauna is shown by the accompanying list of species that have been identified (Table I). The number of examples of each species that has been observed is recorded after each name for the purpose of showing the relative importance of the several members of the fauna; the geologic range and geographic distribution are shown in the several columns.

The geographic and geologic relationships of the fauna.—The geographic and geologic relationships of this fauna are not difficult to determine. Considering first the brachiopods, the list shows that all the forms are found in the Mississippi Valley, although a few species have a wider range. Of these brachiopods, two species, *Spirifer gregeri* and *Spirifer mundulus*, are Lower Burlington. Three species, *Dielasma burlingtonensis*, *Spirifer forbesi*, and *Spiriferella plena*, are confined to the Burlington. Seven species,

Name	Number	Geologic Range				Geographic Distribution			
		Pierson	Fern Glen	Burlington	Keokuk	Iowa	Illinois	Missouri	Other Localities
Corals (unidentifiable)	10								
Crinoidea (exclusive of stems)									
Dizygocrinus rotundus? Shumard	1			*		*	*	*	
Dorycrinus unicornis Owen & Shumard	1			*		*		*	New Mexico
Platycrinus sp.	2	*	*	*		*	*	*	
Unidentifiable fragments	15								
Blastoidea									
Cryptoblastus melo Owen & Shumard	3			*		*	*	*	
Bryozoa									
Fenestelloid fragment									
Brachiopoda									
Athyris lamellosa Leveille	2	*	*	*	*	*	*	*	Indiana, Kentucky, Ohio, New Mexico, Nevada, Wyoming, Europe
Brachythyris suborbicularis Hall	8			*	*	*	*	*	Indiana
Choneles multicostus Winchell	2		*	*		*		*	Tennessee
Cliothyridina prouti Swallow	1		*			*	*	*	New Mexico
Cyrtia? inexpectans? Weller	1				*			*	
Dielasma burlingtonensis? White	2			*		*		*	Nevada
Leptaena analoga Phillips	1	*	*	*		*	*	*	Ohio, New Mexico, Nevada, Utah, Wyoming, Nova Scotia
Productus fernglenensis Weller	10	*	*					*	
Pseudosyrinx sp.?	2	*	*	*	*	*	*	*	
Ptychospira sexplicata White & Whitfield	1		*			*	*	*	
Rhipidomella burlingtonensis Hall	32	*		*		*	*	*	Utah?
Schizophoria swallovi Hall	16	*		*		*	*	*	
Spirifer forbesi Norwood & Pratten	1			*		*	*	*	
Spirifer gregeri Weller	16			*				*	
Spirifer mundulus Rowley	1			*				*	
Spirifer shepardi Weller	104	*						*	
Spiriferella neglecta? Hall	1				*	*	*	*	
Spiriferella plena Hall	1			*		*	*	*	
Syringothyris sp.?	2		*	*	*	*	*	*	
Pelecypoda									
Aviculopectan sp.?	1			*		*	*	*	
Conocardium sp.?	1			*		*	*	*	
Gastropoda									
Euomphalus latus Hall	6			*		*	*	*	Ohio
Platyceras obliquus? Keyes	1			*		*		*	
Platyceras paralius? White & Whitfield	1		*	*		*		*	Ohio

For range and distribution see *U.S.G.S. Bulletin 153; Illinois State Geological Survey, Monograph I;* Walker Museum Collection.

Athyris lamellosa, *Brachythyris suborbicularis*, *Leptaena analoga*, *Ptychospira sexplicata*, *Rhipidomella burlingtonensis*, *Schizophoria swallovi*, and *Chonetes multicostus*, are not limited to the Burlington; but the Lower Burlington seems to be the upper limit of *Chonetes multicostus*, *Leptaena analoga*, and *Ptychospira sexplicata*, while *Rhipidomella burlingtonensis* and *Schizophoria swallovi* are not found above the Burlington. Two species, *Cliothyridina prouti* and *Productus fernglenensis*, are found typically in the Fern Glen, and one species, *Spirifer shephardi*, is typical of the Pierson limestone of southwestern Missouri, which may be the equivalent of the Fern Glen. The Fern Glen commonly has been classed as uppermost Kinderhook, but it is altogether probable that it should rather be considered as lowermost Osage. Species of the two genera *Pseudosyrinx* and *Syringothyris* are found in the Burlington. One species, *Cyrtia inexpectans*, which is very rare, has been described from residual chert in Missouri, supposed to be of Keokuk age, and another species, *Spiriferella neglecta*, is found in the Keokuk, but these two species are the least certainly identified of any of those recorded.

The brachiopods of the foregoing list are clearly related to those of the early Osage faunas of the Mississippi Valley, as these faunas are developed in Iowa, Illinois, and Missouri, and the formation from which they have originated may be certainly correlated as not younger than the Burlington limestone, and in all probability as Lower Burlington.

The other elements of the fauna confirm the correlation suggested by the brachiopods. The abundance of crinoidal remains immediately suggests the Burlington limestone. Both *Dizygocrinus rotundus* and *Dorycrinus unicornis* are typical Burlington crinoids. *Platycrinus* is also found in the Burlington, though it is not confined to that formation. The blastoid *Cryptoblastus melo* is another member of the Burlington fauna and is quite limited in its geologic range. The gastropod *Euomphalus latus* is another characteristic Burlington species, and both species of *Platyceras* recorded are reported from the Burlington limestone. The corals, bryozoans, and pelecypods which have been recorded have not been specifically identified, but all the genera recognized are known to be present in the Burlington.

The place of origin of the bowlders.—As Montclare is 165 miles in a northeasterly direction from the nearest known Mississippian outcrop in the Mississippi Valley, the question at once arises: From where were these Mississippian bowlders transported by the glaciers? The general direction of ice movement in the Chicago region during the last glacial epoch was somewhat west of south, the published records of the directions of glacial striae west of the city showing directions varying from S. 57° W. to due west.[1]

Considering the known direction of glacial ice movement, the first inference is that the bowlders may have been transported from the known Mississippian outcrops in Michigan, but a careful consideration of the Mississippian formations of that state and of their faunas makes such an origin highly improbable.

The Mississippian section of Michigan as given by Lane[2] has been followed by all later writers.

In this section the following subdivisions are recognized:

Bayport or Maxville limestone: Light and bluish cherty limestones and calcareous sandstones.

Michigan series: Dark or bluish limestones and dolomites, with gypsum and blue or black shales; some reddish or greenish shales and dark or red sandstones.

Marshall sandstone: White and red sandstone, often pyritic, peanut conglomerates, sandy shales, whetstones, and red shales.

Coldwater series: Blue shales with nodules of iron carbonate, sandstone, subordinate streaks of fine-grained limestone, black shale at the base.

Berea sandstone: White sandstone, nowhere exposed in the state.

The published list of fossils from these Michigan formations[3] shows them to be faunally related to the Mississippian of Ohio rather than to the Mississippi Valley formations. Writers are not altogether in accordance regarding the correlation of these formations, but, giving the widest possible latitude, the Montclare bowlders must have been derived from a formation whose age was

[1] *Chicago Geological Folio*, pp. 506.

[2] *Annual Report, Geological Survey of Michigan*, 1908, pp. 74–86. (1909.)

[3] *Geological Survey of Michigan*, Vol. VII, Part II, pp. 253–70.

included within the time of deposition of the Coldwater, Marshall, and Michigan formations of Michigan. The published faunal lists from all these formations are made up largely of pelecypods, and from all the available lists a single species, *Spirifer forbesi* (and this identification is admitted to be very questionable), is recorded from the Michigan series, which has been identified in the Montclare collection. Even if the identification of this species from Michigan is correct, it is still quite evident that the Montclare bowlder fauna has no relationships with the Michigan Mississippian which are worthy of consideration. Furthermore, the lithologic character of the Montclare bowlders is totally different from that of any of the Michigan formations.

From the foregoing consideration of the faunal and lithologic characteristics of the Mississippian formations of Michigan it may be assumed as a demonstrated fact that the Montclare bowlders were not transported from across Lake Michigan to their present resting-place.

The only alternative conclusion in regard to the source of these bowlders is that they were originally in place at no great distance from where they now lie. Such a conclusion is further confirmed by the physical condition of the bowlders themselves. They are angular in outline and exhibit much less wear than most of the associated bowlders. The present weathered condition of the bowlders is probably original weathering accomplished before they were moved by the glacier. This is suggested by the different degrees of weathering of the bowlders themselves and by the different surfaces of the same bowlders. Furthermore, the other bowlders of similar composition which were buried with the Mississippian bowlders in the glacial débris are still essentially unweathered, even upon their surfaces.

Conclusions.—A study of these Montclare glacial bowlders of Mississippian age seems to establish the following important conclusions:

1. There existed, previous to the last glacial advance, an outlier of Mississippian rocks in northeastern Illinois, probably resting on limestone of Silurian age. The remnants of such an outlier may well be in existence, completely buried at the present time by

glacial drift. The actual position of this outlier cannot now be determined, but it was at no great distance from the present position of the bowlders and may well have been within the present limits of Chicago.

2. The limestone comprising this Mississippian outlier contained a prolific fauna of brachiopods, crinoids, and other forms of life, every species of which, so far as they have been certainly identified, is present also in the rocks of lower Osage age in the Mississippi Valley. The whole association of species suggests a very definite correlation of these Mississippian rocks with the Lower Burlington limestone of western Illinois, Iowa, and Missouri. There is no suggestion whatever of any faunal connection with the Mississippian formations of Michigan.

3. On the basis of the two foregoing conclusions, the extension into northeastern Illinois of the Mississippian sea, which occupied the Mississippi Valley region in early Osage time, may be assumed.

"SOME EFFECTS OF CAPILLARITY ON OIL ACCUMULATION" BY A. W. McCOY[1]

DISCUSSION BY

C. W. WASHBURNE
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Students of petroleum are indebted to Mr. McCoy for the three useful experiments in this paper. His first conclusion is that oil may accumulate in the larger pores and other spaces of rock, regardless of structure. This fact had been recorded previously in the occurrence of oil in lenticular sands, and I had shown its theoretical necessity.[2] The additional experimental evidence is most welcome. The main argument of the paper is an attempt to show that capillary action possibly may lift the strata into anticlines. This idea appears impossible for four reasons.

First, the pressures created by capillarity are exerted by fluids in open spaces which communicate, more or less deviously, with the ground surface. The perfection of this communication through shale is of the same order as the perfection of transmission of the capillary pressures (assuming that these exist) that are transmitted through shale into sandstone. Moreover, any pressures in the fluids in sandstones are exerted through all spaces, laterally as well as vertically, and would be so equalized through the entire bed of sand that only a local hydraulic gradient would be left to deform the sand. That such slight difference of pressure is unable to tilt a sand need not be argued. Even if the capillary pressures could deform a sand, they would not disturb lower sands along the same axis or lift any of the underlying strata.

Secondly, the amount of pressure available under Mr. McCoy's assumed conditions (p. 802) would not be "the difference in the

[1] *Jour. Geol.*, XXIV (1916), 798–805.

[2] C. W. Washburne, *Transactions A.I.M.E.*, L, 831.

capillary pressures of oil and water for that size of opening." It would be only (*a*) the pressure exerted by the water-oil surfaces beneath the oil, less (*b*) the pressure of the oil-gas surfaces on the hemiglobules of oil that are being forced out of the small capillaries into larger spaces. Since (*a*) and (*b*) are of similar magnitude, their difference, amounting only to a fraction of an atmosphere, cannot be considered a cause of rock deformation.

In other words, Mr. McCoy takes a wrong basis for his calculation of capillary deforming force, and this nullifies the calculation at the end of his paper.

Thirdly, the amount of capillary pressure exerted in a group of tubes of variable size and having many lateral connections, as in rock, cannot exceed the pressure in the largest of these tubes plus the head required for an adjusting flow of gas or liquid through the lateral connections from the finer to the larger pores. If shale is cut by minute open joints or fissures, the low capillary pressures in the latter must limit the effective capillary pressure per square inch in all connecting pores.

Pores that are completely closed above the point of the highest liquid-gas surface within them would feel the complete pressure produced by that surface. Capillary action in completely inclosed pores would not contribute to the general pressure or affect the problem under discussion. In all connected pores, the general capillary pressure could not rise appreciably above the minimum capillary pressure, determined in the largest pores or joints.

I believe that the second and third arguments reduce the probable effective capillary pressure, under the conditions of Mr. McCoy's problem, to a maximum of one or two atmospheres, if the rock is cut by any minute open joints or large pores. Certainly the pressure of 200 atmospheres, which he deduces, is out of the question as a general capillary pressure in rock.

Fourthly, there is no definite orientation to capillary pressures in rock-pores. They push and pull every way and tend to balance each other. The ideal distribution of water, gas, and oil assumed by Mr. McCoy would cause a small capillary pressure of definite

orientation, but the assumed distribution is improbable. The probable original distribution is a sand filled mostly with water and imbedded in shale the pores of which are filled with water, oil, and gas, without any regularity or order.

The three useful experiments so carefully described by Mr. McCoy are worthy of careful study by students of oil, and I trust that we may have more experiments from the same author.

Petrological Abstracts and Reviews

ALBERT JOHANNSEN

BOWEN, N. L. "The Crystallization of Haplobasaltic, Haplodioritic and Related Magmas," *Amer. Jour. Sci.*, XL (1915), 161–85.

The terms haplobasaltic, haplodioritic, and so on, are applied by the writer to simple (pure) artificial mixtures of feldspars of various compositions, and diopside. He uses the rock names according to the best and most recent practice. Various mixtures of these substances were studied by the quenching method of thermal analysis, that is, by sudden chilling at known temperatures, and the material was studied microscopically. No attempts were made to study the optical properties of the minerals formed, it being necessary only to distinguish diopside from plagioclase in these experiments, the results of which are plotted in numerous diagrams. From his results the writer concluded that crystallization controls differentiation in the subalkaline igneous rocks.

BOWEN, N. L., and ANDERSEN, OLAF. "The Binary System MgO-SiO_2," *Amer. Jour. Sci.*, XXXVII (1914), 487–500.

A study of equilibrium in the binary system MgO-SiO_2 by the method of quenching. Forsterite (Mg_2SiO_4) and clinoenstatite ($MgSiO_3$) were found capable of existing in contact with liquid in the binary system. Clinoenstatite was the only stable form of $MgSiO_3$ found. It has no true melting-point, but at 1,557° breaks up into forsterite and liquid. At 1,577° the forsterite dissolves. There is no eutectic between these two compounds.

BOWEN, N. L. "The Ternary System Diopside-Forsterite-Silica," *Amer. Jour. Sci.*, XXXVIII (1914), 207–64.

An investigation of various mixtures of silica, calcium carbonate, and magnesia. It was found that the systems diopside-silica and diopside-forsterite show the simple eutectic relations; forsterite-silica shows one intermediate compound (clinoenstatite) unstable at its melting-point; and clinoenstatite-diopside forms an unbroken series of solid

solutions, corresponding to the monoclinic pyroxenes. The triangular diagram, therefore, shows only three boundary curves and one ternary invariant point. The writer shows that crystallization may proceed according to two different methods, and the importance of distinguishing between them is discussed. The optical properties of the pyroxenes are discussed at some length; extinction angles, refractive indices, and optic axial angles are measured and the orientation is determined.

BOWEN, N.L. "Crystallization-Differentiation in Silicate Liquids," *Amer. Jour. Sci.*, XXXIX (1915), 175–91.

Laboratory experiments showed that olivine and pyroxene crystals sink and tridymite floats in artificial melts of diopside, forsterite, and silica. From the rate of sinking, the viscosities of the melts were found to increase with increase in silica.

COLLINGBRIDGE, HARVEY. "The Determination of the Maximum Extinction Angle, Optic Axial Angle, and Birefringence in Twinned Crystals of Monoclinic Pyroxenes in Thin Section by the Becke Method," *Mineralog. Mag.*, XVII (1914), 147–49.

Gives a method for determining various optic properties by observations on twinned crystals which show the emergence of an optic axis in one portion.

COLLINS, W. H. *The Huronian Formations of Timiskaming Region, Canada.* Museum Bull. No. VIII, Geol. Surv., Dept. Mines, Canada. Ottawa, 1914. Pp. 27, figs. 3, pls. 1.

CROSS, WHITMAN. *Lavas of Hawaii and Their Relations.* U.S. Geol. Surv., Prof. Paper 88, Washington, 1915. Pp. 97, map 1, pls. 2, fig. 1, bibliography.

The writer describes, with considerable space devoted to the norms, various olivine-bearing and olivine-free-, bronzite-, picrolitic-, nephelite-, and melilite-nephelite-basalts, limburgites, soda-trachytes, trachyandesites, a kauaiite or oligoclase-augite-diorite, some basalt tuffs, and a

gabbro. Forty-three chemical analyses are given, and in most cases the normative minerals are computed. In the general discussion the characteristics, chemical compositions, normative compositions, the relations of norms to modes, and the classification are considered. Twenty-two pages are devoted to the distribution of the rocks in the Hawaiian Islands and of analogous rocks elsewhere in the world. The writer discusses the Atlantic and Pacific provinces, and the alkalic and calcic series (alkali and alkali-lime series of Rosenbusch), and concludes with a discussion of differentiation in the Hawaiian magmas.

CROSS, WHITMAN. "On Certain Points in Petrographic Classification," *Amer. Jour. Sci.*, XXXIX (1915), 657–61.

An answer to several criticisms of the C.I.P.W. system of rock classification.

DALMER, K. *Erläuterungen zur geologischen Spezialkarte des Königreichs Sachsen.* Sektion Treuen-Herlasgrün, Blatt 134. 2d ed. revised by E. Weise and A. Uhlemann. Leipzig, 1913. Pp. 58, pl. 1.

Picrite, diabase, granite, quartz-porphyry, mica-porphyrite, various contact metamorphosed schists, and sediments are described.

DALY, REGINALD A. *Origin of the Iron Ores at Kiruna.* Vetensk. och Prakt. Undersök. i Lappland. Stockholm, 1915. Pp. 35, figs. 4.

Expresses the view that the "inclusions" of ore in the Kiruna quartz-porphyry, are endogenous, and represent "frozen-in" units of differentiation. The accumulation of such ore-masses by gravity is thought to be the cause for the origin of the main ore bodies.

DALY, REGINALD A. *Geology of the North American Cordillera at the Forty-Ninth Parallel.* Mem. 38, Dept. Mines. Ottawa, 1912. Pp. 840, maps 17, pls. 73, figs. 42.

Although the date on the title-page of this important memoir is 1912, and the date of transmission 1910, it was not distributed until 1914. In the meantime Daly's *Igneous Rocks and Their Origin*, which contains a much fuller statement of the theories expressed in chaps.

xxiv to xxviii, appeared. It is almost impossible in the space available here, to abstract a book of this character. The Table of Contents alone covers 15 pages, and a synopsis given by the author 8 pages.

After describing the area covered, the author shows the various subdivisions into which the Cordilleras have been divided, and suggests various additions and changes. Then follow descriptions of the stratigraphy and structure of the Clarke, MacDonald, Galton, Purcell, and Selkirk mountain systems, and the Rossland, Christina, Midway, Okanagan, Hozomeen, Skagit, and other ranges. In chaps. ix to x the Purcell lava and associated intrusives are described. The differentiation in the Moyie sill is ascribed to the assimilation of quartzites, and the writer offers proof of this as well as of gravitative differentiation. A great number of chemical analyses are presented. The descriptions of the rocks are given in a manner which might well be followed by other petrologists, namely that of giving the mode of the rock as well as the norm. Further, it is advisable, as is here done, to indicate whether the mode was determined by the Rosiwal method, or by recalculation of the analysis and comparison with the thin section. Pages 677 to 791 are mostly theoretical, and deal with the theory of igneous rocks, classification of igneous bodies, mechanics of batholithic intrusion, differentiation, classification of magmas, etc.

The report is unusually interesting, not only in the theoretical part, but also in the descriptive portions, which in most geologic reports have a soporiferous effect.

DALY, REGINALD A. "Problems of the Pacific Islands," *Amer. Jour. Sci.*, XLI (1916), 153–86, pl. 1, figs. 38.

A plea, given at the meeting of the American Association for the Advancement of Science at San Francisco last August, for the establishment of a central bureau for the comprehensive exploration, from a scientific standpoint, of the Pacific Islands. It is estimated that the cost of such a project will be from $800,000 to $3,000,000, depending upon the thoroughness of the work, and that it will require about ten years of time for the field work, and an additional five or ten years for systematizing and publishing the results. The writer presents a number of the problems which should be solved.

DRYSDALE, CHARLES W. *Geology of Franklin Mining Camp, British Columbia*. Mem. 56, Geol. Surv., Dept. Mines. Ottawa, 1915. Pp. 246, pls. 23, figs. 16, bibliography.

A report on a mining camp in the Yale District in south-central British Columbia. The Franklin group contains the oldest rocks in the district, consisting of metamorphic tuffs, quartzites, and argillites, the latter carrying Paleozoic fossils. The rocks may represent early marine coastal conditions of sedimentation and igneous activity prior to the submergence and eastward transgression of a Carboniferous sea. At the close of the Paleozoic the main folding and metamorphism of the region took place, and the Franklin District thereafter remained above the sea. During the Jurassic period there came the intrusion of a granodiorite batholith beneath a considerable cover of sediments. It did not reach the surface. The Cretaceous period was one of long-continued denudation, laying bare great thicknesses of Paleozoic rocks and even exposing the underlying Jurassic batholith in places. At the close of the Mesozoic the whole Cordillera was uplifted and the Valhalla granite was probably intruded. The early Tertiary was a period of regional sinking accompanied by some volcanic activity. It closed with the tilting of the Kettle River formation, and a new cycle of erosion started. At this time also there came the intrusion of monzonite. During the Miocene there came intrusions of syenite, followed by pyroxenite and augite-syenite, pulaskite-like dikes, and trachyte flows. Regional uplift closed the Tertiary. During the Pleistocene all except a few of the highest peaks of the Cariboo Range were covered by the Cordilleran ice sheet.

A number of chemical analyses of the igneous rocks are given.

ESKOLA, PENTTI. *On the Petrology of the Orijärvi Region in Southwestern Finland*. Bull. com. géol. Finlande, No. 40. Helsingfors, 1914. Pp. 277, pls. 6, maps 2, figs. 55, bibliography.

This interesting bulletin gives an account of the petrology of a series of Archean metamorphic rocks in the vicinity of Orijärvi. After a short geologic history of the region, the author gives careful and detailed petrographic descriptions of various granites, magmatites, pegmatites, diorites, gabbros, hornblendites, aplites, peridotites, amphibolites, leptites, and limestones. He then describes the exogenic contact-zones of the oligoclase-granite, and gives petrographic determinations of the

cordierite-anthophyllite, quartz-cordierite-, cordierite-, and andalusite-quartz-mica-rocks, cordierite-gneiss, plagioclase-biotite-gneiss, cummingtonite-amphibolite, and the skarn rocks. A great many chemical analyses are given, and they are recomputed into the norm as well as into Osann's system. Further, all analyzed rocks whose mode could be determined under the microscope have been recomputed into the mode, an example which might well be followed by petrographers in this country.

FENNER, CLARENCE N. "The Stability Relations of the Silica Minerals," *Amer. Jour Sci.*, XXXVI (1913), 331–84.

The following inversion-points were determined at atmospheric pressure.

870° ± 10° quartz ⇆ tridymite
1470° ± 10° tridymite ⇆ cristobalite

Velocity of transformation very slow.

α-quartz → β-quartz 575°
β-quartz → α-quartz 570°
α-tridymite → β_1-tridymite 117°
β_1-tridymite → β_2-tridymite 163°
α-cristobalite → β-cristobalite 274° to 220°, depending upon the previous heat treatment.
β-cristobalite → α-cristobalite 240° to 198°, depending upon the previous heat treatment.

The transformation in the last six cases takes place promptly.

The melting-point of cristobalite is *ca.* 1,625°, while quartz is at least 155° lower.

FERMOR, L. LEIGH. "Preliminary Note on Garnet as a Geological Barometer and on an Infra-Plutonic Zone in the Earth's Crust," *Records Geol. Surv., India*, XLIII (1913), 41–47.

A comparison of the specific gravities of certain garnet-bearing rocks with the specific gravities of the same magmas crystallizing in normal minerals showed that the garnet-bearing rocks occupied from 10 to 20 per cent less room. From this the author concludes that garnet-bearing rocks, such as kodurite, eclogite, etc., are high-pressure forms of normal rocks. He therefore postulates the existence, below normal plutonic rocks, of a shell characterized by garnets wherever a sesqui-oxide radicle exists. For this shell he proposes the term "infra-plutonic." Another

mineral of this zone is diamond. Under normal conditions the author thinks a relief of pressure would liquify a certain portion of the infra-plutonic rocks which, on being intruded into the higher zones of the earth's crust, would there solidify under less pressure as a normal plutonic rock. Only under exceptional circumstances, for example when the isogeotherms are lowered more rapidly than the pressure, will the garnet-rock cool in its infra-plutonic form, to appear later by erosion. The author considers this garnet-shell to be continuous around the earth and potentially liquid, subject to local fusion and the formation of reservoirs wherever there is a reduction of superincumbent pressure.

Applying this theory to meteorites, he thinks the chondrules, which occur in so many stony varieties, were formerly garnets, and that cliftonite in the iron meteorites was formerly diamond.

FETTKE, CHARLES REINHARD. "The Manhattan Schist of Southeastern New York State and Its Associated Igneous Rocks," *Ann. N.Y. Acad. Sci.*, XXIII (1914), 193–260, pls. 8, bibliography.

The Manhattan schist, the youngest of the three crystalline metamorphic formations which form bed-rock in southeastern New York, occurs in a series of closely folded anticlines and synclines, usually unsymmetrical and in many cases overturned tôward the west. The axes of the folds run northeast and southwest and gently dip to the south. The chemical composition and field-relations of the schist show that it is of sedimentary origin, derived from shales, sandstones, and arkoses. These were laid down conformably upon the underlying limestone to a depth of several thousand feet. Later a series of basic rocks—hornblende- and actinolite-schists of dioritic and gabbroic characteristics, and granodiorite-gneiss (better gneissoid-granodiorite, since it was determined to be of igneous origin)—was intruded in the form of sheets and sills. Now came a period of intense folding accompanied by intrusions of granite, aplite, and pegmatite. Later there were intruded various basic rocks—norites and pyroxenites of the Cortlandt series, hornblendite near Croton Falls, and other rocks now altered to serpentine. The pegmatitic intrusions still continued, for these later basic rocks are cut by them in several places.

Reviews

The Origin of the Magmatic Sulfid Ores. By C. F. Tolman, Jr. and Austin F. Rogers. Leland Stanford Junior University Publications, 1916. Pp. 76, figs. 7, pls. 20.

After reviewing the literature bearing on the modes of origin of the various magmatic ore deposits, the authors have proposed as their thesis that "the magmatic ores have in general been introduced at a late magmatic stage as a result of mineralizers and that the ore minerals replace the silicates. This replacement, however, differs from that caused by destructive pneumatolytic or hydrothermal processes in that quartz and secondary silicates are not formed at the time the ores are deposited."

The authors follow the position taken by Bowen in his recent work establishing the process of fractional crystallization as the dominant one during magmatic differentiation. After studying suites of specimens from Sudbury, Ontario, Elkhorn, Montana, Ookiep, South Africa, and Plumas County, California, the conclusion is reached that the ores have been introduced by pneumatolytic means after the formation of the rock-bearing silicates. The authors show clearly that the sulphides are a late magmatic product, that they surround the silicates, cut them with well-defined veinlets, embay them, and penetrate cleavage cracks and contacts with other minerals. The absence of metallic silicates makes it clear that the ores were not introduced as molten material, while the replacement of early formed minerals indicates the presence of mineralizing solutions. The complete absence of reaction rims shows that the replaced material was removed by the same agents which introduced the ores. Selective replacement is shown by the preservation of the original graphic texture of the rocks in the ores. There is also evidence of the alteration of pyroxene to hornblende prior to the introduction of the ore minerals, suggesting the presence of aqueous vapor. The small amounts of hydrothermal alteration present appear to be related to a post-magmatic stage.

The authors conclude that the temperatures involved in the deposition of the ores did not exceed 300 C. to 400 C., but it is unsatisfactory so to limit the temperature without further data than are here presented.

That the temperatures were higher than those of pegmatites is admitted by the writers, but the only thing certain about the temperatures of the pegmatites is that some minerals in some pegmatites formed at temperatures lower than 575° C. The dominance of pyrrhotite as compared with pyrite is recognized, and this indicates a high temperature, since pyrite is less stable than pyrrhotite at such temperatures.

The paper represents an excellent piece of work and is a distinct contribution to the knowledge of magmatic processes. It also serves to emphasize the fact that a great deal must be known concerning the minute textures of rock masses, other than that they are merely in juxtaposition, before positive conclusions may be reached as to the sequence of crystallization.

E. A. STEPHENSON

CHICAGO

Relations of Cretaceous Formations to the Rocky Mountains in Colorado and New Mexico. By WILLIS T. LEE. Prof. Paper, U.S. Geol. Surv. No. 95-C, 1915. Pp. 27–58, pl. 1, figs. 11.

In this paper physiographic principles are applied to certain phases of the stratigraphy of the southern Rocky Mountains. The geographic conditions during the Mesozoic are discussed and a large number of Cretaceous sections are considered. This study indicates that this basin of Cretaceous deposition was deepest in northern Colorado and southern Wyoming, and that the main mass of sediment came from an ancient land farther west. The sections show, moreover, that the sandstone formations near this ancient continent become thinner eastward, toward the present Rocky Mountains, and are replaced by shales. The author concludes that the conformable Cretaceous formations up to and including the Laramie once extended across the present site of the mountains. Downward warping and deposition in this basin was followed by uplift and erosion. This change is believed to mark the close of the Cretaceous. The formations deposited after the uplift (the post-Laramie formations) belong in the Tertiary.

H. R. B.

Review of the Pleistocene of Europe, Asia, and Northern Africa. By HENRY FAIRFIELD OSBORN. Annals N.Y. Acad. Sci., XXVI, 1915, pp. 215–315, figs. 20, tables 4.

This paper is a revision for the German edition of chap. vi of the author's *The Age of Mammals*.

H. R. B.

Geological Relations and Some Fossils of South Georgia. By J. W. GREGORY. Trans. Roy. Soc. Edin., L, 1915, pp. 817–22, pls. 2.

The outcropping rocks are described as consisting of a metamorphic series of probable Ordovician or Silurian age and a series of marine Mesozoic rocks associated with volcanic tuffs. There is no evidence of Cenozoic volcanic activity, and the igneous rocks are not of distinctly Andean types. Suess believed that the Andes extended in a great horseshoe curve through South Georgia to the South Orkneys and Graham Land.

H. R. B.

The Jaw of the Piltdown Man. By GERRET S. MILLER, JR. Smith. Misc. Coll., LXV, No. 12, 1915. Pp. 31, pls. 5.

In 1912 the right half of an apelike jaw, a portion of a human brain case, and other human bone fragments were found in a gravel pit at Piltdown, Sussex, England, associated with an interglacial (early Third?) fauna. Assuming that these remains represented parts of one individual, Woodward established the genus *Eoanthropus*, characterized by the combination in one skull of a human brain case and an apelike jaw.

Miller now compares casts of these fragments with specimens of Pongidae and Hominidae in the National Museum and finds that the brain case shows fundamental characters not known except in the genus Homo, while the other fragments show equally diagnostic features hitherto unknown except among members of the genus *Pan* (chimpanzees). For the Pleistocene species represented by Woodward's *Eoanthropus*, Miller proposes the name *Pan vetus*.

H. R. B.

The Shinumo Quadrangle, Grand Canyon District, Arizona. By L. F. NOBLE. U.S. Geol. Surv., Bull. No. 549, 1914. Pp. 100, pls. 18, fig. 1.

This bulletin presents the results of a detailed study of the western part of the Kaibab division of the Grand Canyon. The section includes rocks of Archean, Algonkian, Cambrian, Mississippian, and Pennsylvanian age. The lower or Unkar group of the Grand Canyon Series (Algonkian), in particular, is treated in considerable detail. The map which accompanies the bulletin represents the first detailed mapping done in the Grand Canyon region.

H. R. B.